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Final Report for Statistical Methods and Tools for UXO Site Characterization on Final Simulated Site

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Executive Summary

This report details the demonstration of statistical tools developed by Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratory to identify preferred geophysical transect designs for sites suspected of containing UXO and to analyze the resulting geophysical anomaly data. The analysis tools developed provide the Visual Sample Plan (VSP) user the ability to identify potential target areas, delineate boundaries of the target areas wherein UXO is most likely, and estimate the anomaly density within each identified and delineated target area. The methods are also useful for providing justification for no further investigation in very large portions of investigation sites.

The PNNL/Sandia characterization design team received information on a simulated munitions site from Mitretek Systems where 4.2” mortars, 155 mm munitions, and differing size precision bombs were used. Mitretek provided varying degrees of information for each impact area in the conceptual site model and the characterization team used the available information to develop geophysical transect survey designs to identify potential targets areas located in each impact area. The resulting anomaly data from the transect designs were analyzed and potential target areas were identified and delineated. Once the potential target areas were identified, delineated and anomaly densities estimated, the truth data was provided by Mitretek and an evaluation of the performance of the statistical methods was conducted. This report summarizes the performance of the statistical tools in identifying and delineating target areas and estimating anomaly density.

The simulated site consisted of 5 major areas (ARA-1, ARA-2A, ARA-2B, SRA-1, and BGR-1) ranging from 6200 acres to 74650 acres in size. Three of the areas were used as artillery ranges, one site was used as a small arms practice range, and the one was a precision bombing range. Multiple transect sampling approaches were requested for each site by the PNNL/SNL team to adequately evaluate the performance of VSP and the geostatistical methods for transect design, target identification and delineation, and anomaly density estimation. Using the most conservative approach for each of the 5 areas, a summary of the target detection and UXO containment with the target area boundaries is shown in Table E1.

Impact Area	Transect Spacing	Density of Target Areas above background	Percent of Site Covered with Transects	Total Number of Target Areas	Total Number of UXO	Number of Target Areas Identified	Number of UXO Contained	Percent of Target Areas Identified	Percent of UXO Contained
ARA-2B	282m	>6	0.71%	9	253	9	253	100.00%	100.00%
ARA-2A	344m	>6	0.60%	3	175	3	175	100.00%	100.00%
SRA-1	204m x 204m	>6	1.94%	None	None	None	None	Correct	Correct
ARA-1	344m	>6	0.66%	7	110	7	110	100.00%	100.00%
BGR-1	483m x 961m	>6	1.20%	24	92049	24	92049	100.00%	100.00%
ARA-2B	282m	<6	0.71%	8	19	1	0	12.50%	0.00%
ARA-2A	344m	<6	0.60%	2	38	1	27	50.00%	71.05%
SRA-1	204m x 204m	>6	1.94%	None	None	None	None	Correct	Correct
ARA-1	344m	<6	0.66%	5	73	1	31	20.00%	42.47%
BGR-1	483m x 961m	<6	1.20%	No target areas with density less than 6 per acre.					

Table E1: Target identification and UXO containment performance of PNNL/Sandia for the conservative designs separated by target density

Major findings and conclusions of this demonstration are summarized below.

- 100% of the target areas where the anomaly density was >6 anomalies per acre above background were identified for all areas where target areas existed.
- 100% of the UXO was contained within the derived target area boundaries for all areas where the target area anomaly density was >6 /acre above background.
- When no target areas existed on a suspected impact area (SRA-1), none were identified.
- For areas where target area anomaly density was very close to background density (<6/acre), success of identifying those target areas was mixed (not a surprise given our transect design criteria).
- Transect width appears to significantly affect the ability to identify target areas, especially those with densities closer to background. The 2 m wide transects performed better than 1 m wide transects.
- Target areas were detected and delineated with very little transect area coverage which ranged from 0.6% to 1.94% .
- Anomaly density estimates for the non-BGR target areas were very accurate (7.6% average accuracy). For the BGR target areas the average accuracy was 20%.
- Simulated target area sizes were not always consistent with the assumed sizes and shapes used to design transects. A unified approach to this should be pursued.
- Some inconsistencies in the simulated anomalies affected the performance of the detection and estimation methods (see Appendix B for detailed description of this issue).

The PNNL/SNL combined approach resulted in a very efficient and consistent overall approach to transect design, target identification and delineation, and anomaly density estimation.

1. Introduction

1.1 Background

The Department of Defense (DoD) is in the process of assessing and remediating closed, transferred, and transferring (CTT) ranges. Many of these sites involve very large geographical areas such that it is often impractical and/or cost prohibitive to perform 100% surveys across the entire site of interest. With over 20 million acres of land where UXO may possibly reside, effective characterization and detection technologies are needed. Statistical sampling methods and tools are needed to support several phases of the characterization and decision making process including optimal sampling designs for target detection, target delineation, anomaly/UXO density estimation, and post-remediation verification.

Statistical tools have been developed under SERDP/ESTCP to support detection, delineation, density estimation, and mapping of unknown target areas where UXO are most likely. Through ESTCP sponsorship, these tools, developed by Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratory (SNL), are being demonstrated on simulated sites and on actual DoD sites suspected of UXO presence. The tools are being deployed via the Visual Sample Plan (VSP) software.

Previously, three simulated sites were studied and the performance of PNNL/SNL tools was evaluated. For each site, the PNNL/SNL team was provided with a site map and some information relative to past site practices. Based on required detection probability rates and likely fragmentation dispersion patterns, the optimal transect spacing was identified and a selected set of geophysical transects were requested and simulated. An independent contractor used their site simulation software and provided PNNL and SNL with all locations along the requested transects where anomalies were detected. PNNL and SNL then applied their target area detection, delineation, and mapping tools. The three site evaluations were performed sequentially with increasing site complexity added as tests progressed. This final report pertains to the fourth and final simulated test site performance evaluation.

1.2 Objectives of the Demonstration and Site Description

This demonstration is the fourth and final demonstration of the methods and tools on a simulated site. The objective was to exercise the tools in such a way as to ensure their applicability on a variety of real sites, given the unknowns that may be encountered at these sites. The site scenario was chosen to simulate reality and the difficulties that will normally present themselves in the practical application of statistically-based characterization tools. This final demonstration site is considerably larger than any of the previous three simulated sites and contains five distinct firing and bombing ranges.

The following scenario is assumed for this demonstration: A large site exists, portions of which were used as firing ranges and other portions were used as bombing ranges.

Boundaries around the general impact areas are known and all target areas were within the suspected impact areas. Nearly all target area locations were unknown with only one exception where prior information on the general location of the target area was provided. A 100% geophysical survey is not feasible due to cost, scale of the site, and accessibility issues.

It is necessary to derive a geophysical transect sampling scheme and apply post-survey analysis methods to 1) Detect all target areas of concern and 2) Delineate (establish a boundary around) each target area or cluster of target areas, and 3) Estimate the anomaly density for each target area or target area cluster.

To ensure that we fully tested out the statistical methods and tools, PNNL/Sandia requested that the following simulated site characteristics be included in the simulated site and were assumed to be components of the site conceptual model (CSM) :

- Multiple munitions used; mortars, projectiles, bombs.
- Multiple target areas; some clustered; some isolated; some singleton targets
- Some areas of the site with different background anomaly density (gradually varying; not very large differences)
- Varying ordnance dispersion pattern models
- An area with unusually high anomaly density but no OE related anomalies.
- Prior information on the general location of some of the target areas as derived from an archived search report or conceptual site model.

The site boundaries and some information regarding site history, munitions used and suspected impact or target areas were provided to PNNL and SNL. After PNNL/SNL designed and requested transects, the site simulators provided a list of anomaly locations identified from the simulated geophysical surveys of the requested transect designs. PNNL and SNL then applied their tools to identify suspected target areas and, in some cases, requested additional transects. The site simulators updated the list of anomaly locations to include those found within the additional transects. Finally, the developed tools were applied to identify target areas, delineate the target areas, estimate anomaly densities, and develop anomaly density maps of the site. Performance was assessed based on the criteria outlined in Sections 3 and 4 below.

1.3 Regulatory and Stakeholder Issues

At the onset of this demonstration, a meeting was held with the Technical Advisory Committee (TAC) consisting of State and EPA regulators as well as Army Corps of Engineers personnel. High level objectives for this demonstration were discussed along with our recommendations for various scenarios that would help test our methods. The TAC provided specific guidance to the ESTCP program manager and to those responsible for simulating the sites and has been cognizant of this particular demonstration. Also, in an effort to support regulator acceptance and technology transfer, a presentation was provided in Las Vegas to an ad hoc EPA/COE committee set up to deal with UXO sites. This presentation included preliminary findings on this simulated demonstration. Efforts to integrate the VSP UXO module with other software and methods for determining target area size and shape characteristic of various munitions' usage were discussed along with additional VSP enhancements.

2. Technology Description

2.1 Technology Development and Application

To advance the state-of the-art in statistical methods and tools to meet its specific needs, DoD invested in three SERDP projects in FY01 at PNNL, Sandia and ORNL. The projects responded to DoD's call for "Statistical Sampling for Unexploded Ordnance (UXO) Site Characterization (CUSON-01-01). Because each phase of characterization supports a different objective with different decision criteria, it quickly became apparent that different statistical methods would be required for each phase of the characterization / remediation / verification process. DoD continued to fund research at PNNL and Sandia to develop statistical methods that addressed different but related phases of the process.

PNNL's methods address SERDP's statement of need for developing statistical sampling methods where 100% surveys are unattainable or cost prohibitive. The innovation of these developments in target detection statistical sampling design methodology allows the stakeholders to explicitly balance the risk of not finding areas of potential UXO contamination when they may be present and the cost of unnecessary or non-optimal searches. These sampling design methods are consistent with systematic planning processes such as the Data Quality Objectives (DQO) process. The target detection design methods focus on determining the number and spacing of transects that will be required to have an acceptably high probability of traversing and detecting target areas of a critical size, shape, and anomaly density. Target areas are defined as areas where UXO are most probable and the number of geophysical anomalies is much higher than in the background.

There are several design parameters (DQO parameters) that affect the probability of detecting a target zone of interest and the feasibility of the sampling design. These include:

- The assumed shape (circular or elliptical) and size (area in m^2 or ft^2) of a target area that must be detected with high probability.
- The required probability that at least one transect traverses some portion of the assumed target area.
- The swath width or footprint of the geophysical sensor used to detect anomalies.
- The transect pattern (parallel, square grid, or rectangular grid patterns can be assumed).
- The spatial orientation (N-S, E-W) of the transect pattern with respect to expected orientation of the target area.

- The anomaly density patterns [A uniform pattern (unchanging density over the target area) or a bivariate normal pattern (highest density at the center of the target area with decreasing density in all directions) are assumed].
- The critical anomaly density threshold value above which a potential target area will be flagged.
- The false negative detection error rate of the geophysical sensor instrument to be used.
- The costs for transect and geophysical sensor setup and sampling/evaluation costs per linear foot of transect.

The effect of varying each of these parameters can be evaluated and the most feasible, cost-effective sampling design can be determined.

2.1.1 Visual Sample Plan (VSP) Software Implementation of Target Detection Sampling

PNNL has incorporated its developments in target detection statistical sampling design methodology into a sampling design software program, Visual Sample Plan (VSP), which has been developed for soil and surface environmental characterization efforts. The U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the Department of Defense (DoD) are co-sponsoring development of the software. VSP allows the user to import or draw a map of the facility site and/or area to be characterized. Figure 1 shows a screen shot from the VSP UXO Target Detection sampling module depicting a hypothetical site with the area where transect sampling is planned. The two windows in the upper left and right of Figure 2 illustrate the VSP dialog box that allows the user to input the DQO parameters listed above and other relevant design parameters. VSP calculates the required transect spacing and the probability of both traversing and detecting a target area of the specified size, shape, and anomaly density. The lower figure in Figure 2 shows the recommended transects generated by VSP for the selected design.

Given the design parameters, VSP will compute the required spacing of transects to achieve the specified probability of traversing the critical target area, calculate the probability of both traversing and detecting the critical target zone if it exists, display the proposed transects on the site map and will output the x,y coordinates of the proposed transects. The user can then conduct a sensitivity analysis by evaluating the effects of the input parameters and their required DQO parameters. These methods and tools allow the project team to balance DQO objectives against costs and other site constraints. After analysis of the transect sampling data, if no target zones are identified and estimated anomaly densities as calculated with geostatistical mapping (see below) are acceptably low, then plans for no further action are considered. If potential target zones are identified through sampling, then the next phase of sampling focuses on defining the boundary of the target zone and developing a sufficiently accurate map of the anomaly/UXO density.

2.1.2 VSP Target Identification flagging routines

VSP's target identification algorithm uses a circular window to calculate the density of anomalies within a certain distance from the center of the window. This window, centered on a transect, systematically moves along each transect of the site and flags the center point of the window located on the transect as an area of high density when the window has more anomalies than expected for background anomalies alone. Because there is often no prior estimate of background anomalies, VSP provides the capability of examining the distribution of densities based on the user defined window diameter. The user can then determine an optimum critical value or background density based on this window size. With the optimum window size and appropriate background density determined, potential target areas are identified. Figure 3 is a screen shot of a sample area with the results from the flagging routine (square boxes) based on the anomalies located on the surveyed transects. The flagged areas represent locations of high anomaly density which could be identified as target areas.

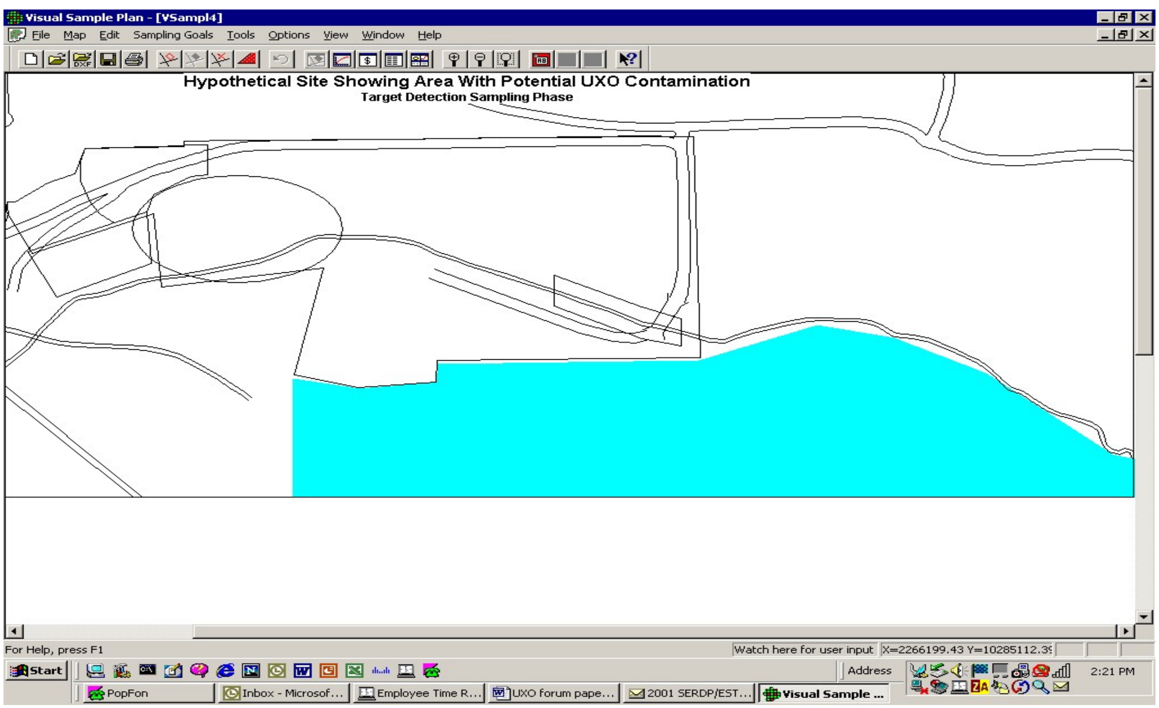


Figure 1: VSP Screen Shot Showing Site Map and Area To Be Surveyed

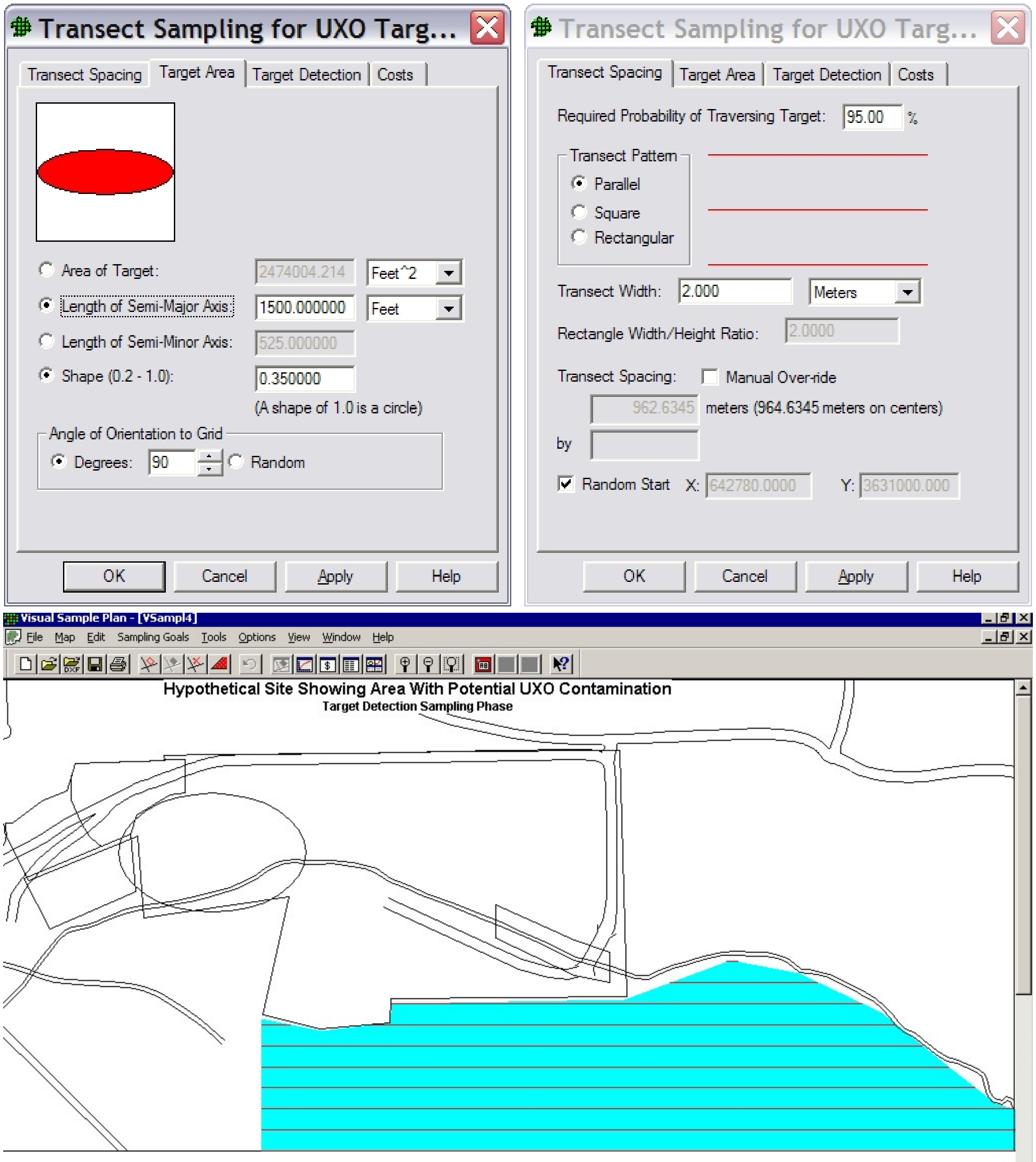


Figure 2: Transect design options and output in VSP. The upper left figure represent the target area assumptions tab and the upper right figure represent the transect design assumptions tab. The lower figure depicts the placed transects in the identified sample area.

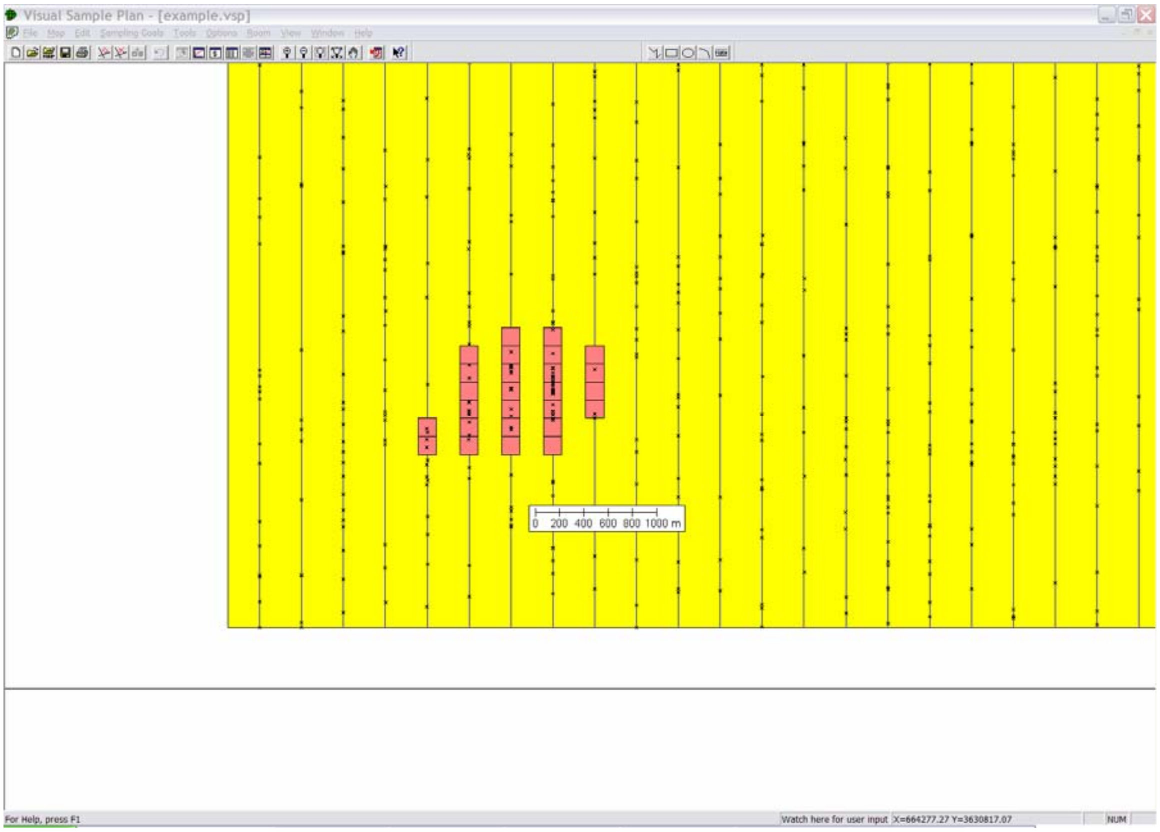


Figure 3: VSP Screen Shot Showing Flagged Areas of High Density

2.1.3 Geostatistics Applied to UXO Issues

Sandia's research extends geostatistical algorithms designed for the analysis and modeling of spatially correlated data to applications in the UXO site characterization arena. The basic idea in the application of geostatistics to UXO applications is that for any site there will only be limited transect sampling and it is therefore necessary to estimate the presence or absence of UXO at unsampled locations and to identify the uncertainty in those estimates. Under SERDP funding, Sandia worked on four separate tasks: 1) development of a theoretical basis for the mapping of UXO contaminated areas as a doubly-stochastic Poisson process; 2) development of a sampling protocol for initial sampling transects and follow-up sampling transects for the practical field characterization of UXO sites; 3) implementation of a data worth approach for determining the optimal location for follow up sampling transects (straight or meandering) and the necessary number of transects to meet site characterization goals; and 4) validation of the procedures against a series of exhaustively known hypothetical and actual field data sets. The work reported here extends this fourth task.

Sandia developed a general approach for integrating prior information with transect data. One means of generating prior information was to use a Poisson process simulator to allow for numerical representation of site conceptual models. This simulator allows the user to include uncertainty inherent in the location and sizes of targets and firing zones as determined from archival information and existing geophysical sampling. Techniques for the optimal placement of transects based on this type of site conceptual model have also been investigated. Cokriging has been evaluated as an updating algorithm to combine the site conceptual model (prior information) with geophysical sampling along transects to produce a map showing the probability of being within a target area at all locations. This probability map can be compared against a design reliability to make decisions (add to dig list or leave as is) for all locations across the site. Initial validation on actual and simulated sites shows that cokriging provides accurate representations of the number of UXO even in the presence of spatially biased prior information. In addition to mapping the probability of being within a target area, techniques have also been developed for the direct mapping of geophysical anomaly density from transect data.

2.1.4 Probability Mapping

For sites with some existing data, it may be advantageous to create maps showing the probability of exceeding a specified intensity of geophysical anomalies per location or the probability of having at least one UXO, or one anomaly of interest, per location. These measures can roughly be qualified as mapping the probability of being within a target area at any location. Typically, areas with higher probability of high anomaly density or UXO occurrence are target areas within a site. These types of maps are especially useful for locating additional sampling transects and allowing the regulator to define the reliability of the characterization decisions made from the available data. Probability values near 0.50 indicate areas of maximum uncertainty with respect to the threshold being considered. As an example, Figure 4, A shows the locations of four sampling transects taken on a hypothetical site created with a doubly stochastic Poisson simulator. For each location along the transect the probability of finding at least one UXO is set to 1.0 (UXO is present) or 0.0 (no UXO are present). In many applications where geophysical surveys are completed prior to any excavation, the probability map may be created showing the probability of an *anomaly of interest* existing, or not existing, at any location. An anomaly of interest is an anomaly that exceeds a prescribed geophysical threshold value or meets a certain fitness value when evaluated against the simulated geophysical response for different munitions believed to exist at the site.

Probability mapping can be completed using only the information obtained from the transects as designed using VSP and the appropriate design parameters (see above), or the geostatistical algorithms can be used to merge both the transect data and more subjective information on the location and extent of target areas as obtained from Archival Search Reports (ASR's), aerial imagery and/or simulations of UXO locations based on the conceptual site model (CSM). For the example calculation shown in Figure 4, prior information in the form of probabilities on the location of two targets and a firing zone as derived from the CSM is shown in Figure 4, B.

Figures 4, C and D show the results of estimating the probability of at least one UXO across the site. Estimates are only made up to a distance away from the nearest sample point that is equal to the range of spatial correlation as defined by the sample data obtained in the transects. Figure 4, C shows the estimates made using only the transect sample data. Figure 4, D integrates the conceptual site model information (Figure 4, B) with the sample transect data by using the geostatistical estimator as a Bayesian operator. Note the change in size and shape of the areas of near 0.50 probability (green areas) when the estimates are constrained to the conceptual site model information. Areas with probability values near 0.50 are areas of greatest uncertainty and correspond to transition zones between targets and background. Focused sampling in these areas can efficiently determine the boundaries of the target areas.

2.1.5 Density Mapping

Similar to the probability mapping, estimates of geophysical anomaly density can be made across the site based on limited data. The same geostatistical estimation algorithms (kriging and cokriging) used for probability mapping can incorporate the site-specific calibration of the geophysical instrument into the density mapping of the site. Density mapping can be used with limited or even larger amounts of data to accurately estimate the geophysical anomaly density in smaller areas of the site prior to developing a final detailed survey map or dig list. Density estimation requires that some finite area of the site be defined and then the number of anomalies per area is estimated. Typically, we have used a regular grid where each cell in the grid is an equal area and the number of anomalies per grid cell is estimated. Grid cell areas have ranged from 625 to over 5000m^2. Even though the density estimates are often made on grid cells with areas much less than one acre, the results are generally reported in units of anomalies per acre as this seems to be the standard unit of measure in the UXO community.

Density estimation also allows for target area boundary delineation. A density contour is selected and areas of the site where the estimated density exceeds this contour are defined as being within the target area. While this target area delineation approach is more straightforward than the probability mapping approach, it is a deterministic approach and does not allow the decision maker any direct consideration of reliability in setting the extent of the target boundary.

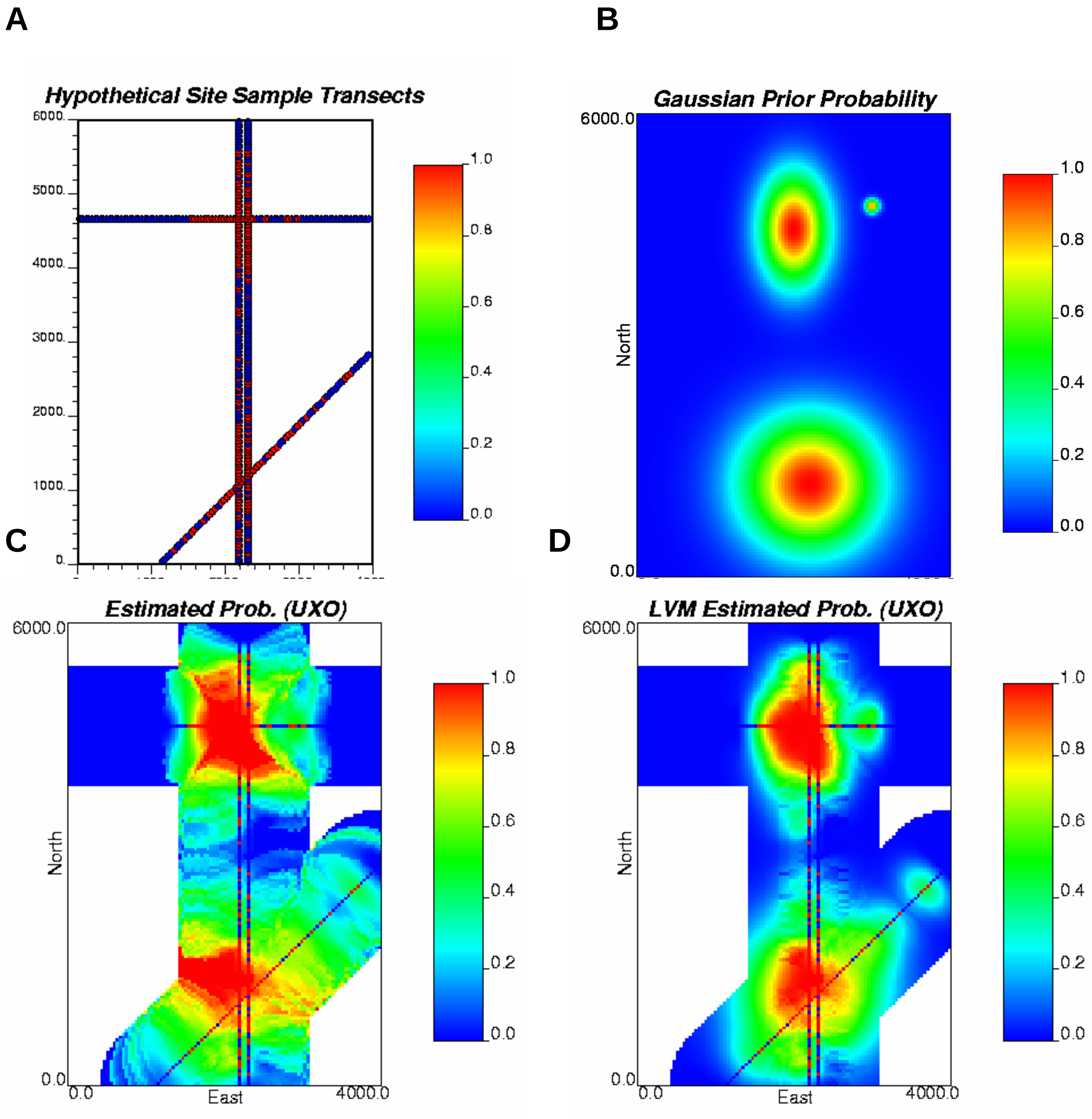


Figure 4: Locations along sample transects (A) are coded as 1.0 (at least one UXO exists) or 0.0 (no UXO exists). The conceptual site model (B) provides estimates of the probability of having at least one UXO at any location based on surface surveys and historical records. The probability of at least one UXO existing is then mapped to all locations that are within the spatial correlation range of a transect sample using just the transect data (C) and integrating the conceptual site model with the transect data (D). The color scale shows the probability of at least one UXO at every location.

2.2 Previous Testing of the Technology

Three tests were conducted previously on simulated sites with increased complexity added for each of the tests. In each case, some initial site information was provided to both the PNNL and SNL teams, transects were requested and anomaly data from the transects were provided by Mitretek. In all three cases, the PNNL and SNL teams worked independently and results are reported for each team. A summary of the results of each of these tests is provided Table 1. A complete review of these sites and the results can be read in the demonstration plan for this study.

In each of the three scenarios PNNL identified all the target areas, contained 100% of the UXO in each of the identified target areas, and minimized the amount of area selected outside of the actual target areas. PNNL also demonstrated that the VSP user can choose from parallel, square grid, or rectangular grid transect spacing to apply in different regions of the sample area.

Scenario	% of Targets Identified	% of the UXO Identified	% of the sample area covered by transects
Simulation 1	100%	100%	0.77%
Simulation 2	100%	100%	0.84%
Simulation 3	100%	100%	0.26%

Table 1: Previous Performance of PNNL's independent analysis of the first three simulated sites.

The Sandia approach to identifying transect locations was an adaptive one with prior information on the site dictating where the initial transects would be located. For each site these initial transects were obtained and then additional transects were requested. At each site, the probability of the anomaly density exceeding a threshold value was mapped onto a relatively fine grid using the geostatistical algorithms. Then a probability contour was selected and all cells in the map above that contour level were identified as being part of the target. The results are given in terms of the design reliability which is the complement of the probability of being within a target. For example, the map showing the probability of being within a target is created, a probability contour level of 0.05 is selected and all locations with a 5 percent or greater chance of being within a target are classified as the target region. The 5 percent probability contour serves as the boundary of the target. The design reliability is the complement of the probability threshold or 95 percent in this example.

For each of the previous simulated sites, the percent of the target areas found, the percent of the UXO within the target boundaries and the percent of the site incorrectly identified as target areas (false positives) are recorded. For each one of these performance measures, the design reliability necessary to produce these results is also identified. The performance measures and the design reliabilities are presented in Table 2. In general, the higher the design reliability the more conservative the decision and the greater the number of targets and UXO that are identified. The flip side of this relationship is that more false positives are created as the decision becomes more conservative. Results in

Table 2 show a range of design reliabilities that produced the same results in terms of identifying targets and UXO. False positive rates were kept to 20 percent or less at alls sites.

Mitretek Site	Targets Found (%)	Design Reliability	UXO in target bounds (%)	Design Reliability	False Positives (%)	Design Reliability
1	100	>= 0.50	100	>= 0.50	20	<= 0.80
2	100	>= 0.85	93	>= 0.85	5	<= 0.85
3	80	>= 0.90	94	>= 0.80	10	<= 0.90

Table 2: Summary of Sandia results for the three previous simulated sites.

3. Demonstration Design

3.1 Performance Objectives

This fourth simulated site demonstration introduced more challenging site conditions and scenarios to evaluate the effectiveness of the combined tools of PNNL and Sandia. Contrary to the previous three simulated site demonstrations, this demonstration took an integrated approach between PNNL and Sandia as shown in the following flow-diagram (Figure 5). Specific performance objectives for this study are listed in Table 3.

Integrated Methods/Tools Approach

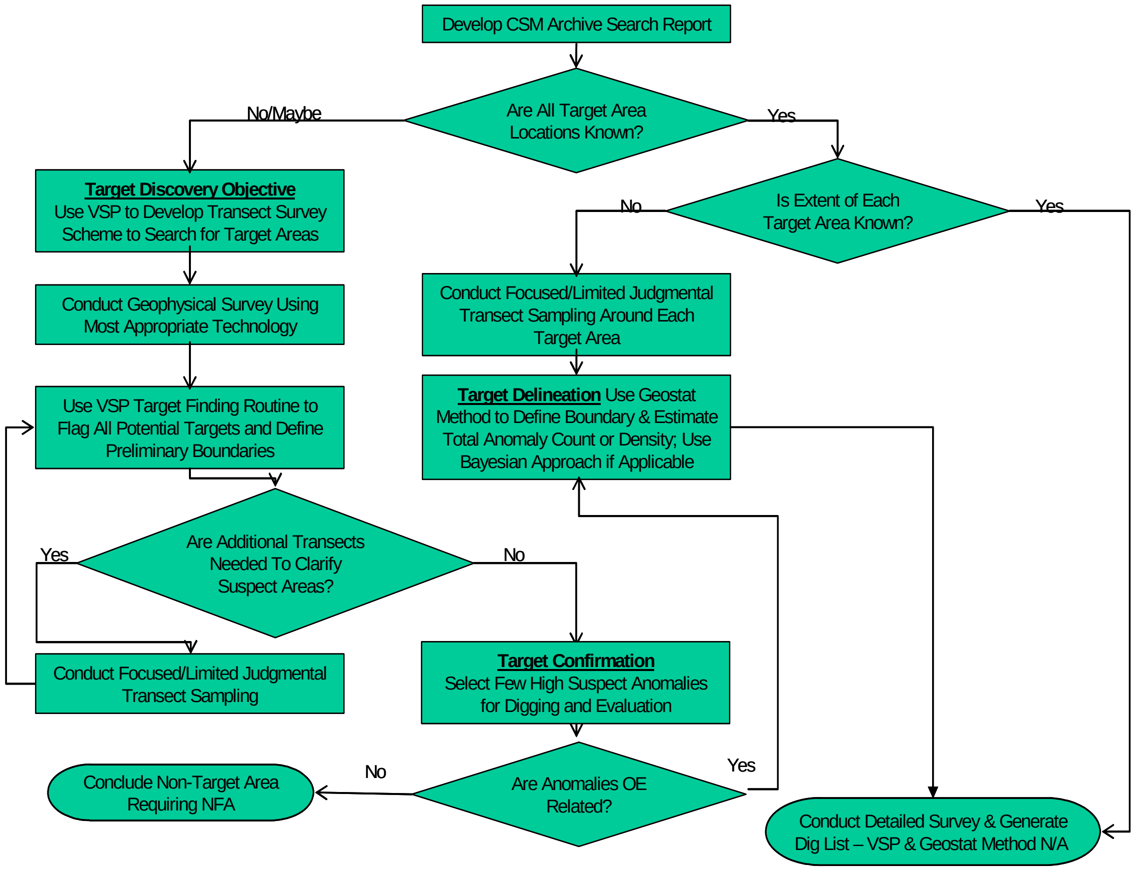


Figure 5: Integrated PNNL/Sandia Methods/Tool Approach.

Type of Performance Objective	Primary Performance Criteria	Expected Performance
Quantitative	% of UXO encompassed with suspected bounded areas	100% unless in completely inaccessible areas
	% of Target areas encompassed within suspected bounded areas	100% unless in completely inaccessible areas
	Accurate distinction between target areas and high density non-OE related areas.	No non-target areas flagged as target areas
	% of land area covered by transects	<10%
	Accurate estimate of anomaly density for each suspected target area	Within 20%
Qualitative	Minimal amount of area outside of true target areas included in bounded suspected target areas.	Minimize
	Ability to appropriately handle inaccessible areas and inexact transects (transects that are not perfectly parallel)	General Use Demonstration

Table 3: Performance objectives for PNNL/Sandia team

3.2 Test Site

This simulated site contains five different areas with a combined area of over 300 sq. km as designed by Mitretek. Mitretek provided a conceptual site model (CSM) scenario for each of the five impact areas and the CSM suggested that target areas existed in each of these impact areas. However, the information about target areas varies from approximate location to no knowledge of a location. The rest of the site has no known indications of target areas.

3.3 Testing and Evaluation Plan (DQO Approach)

The approach for testing and evaluating the performance of these tools is outlined below by taking a Data Quality Objectives (DQO) approach to the problem.

3.3.1 Problem Statement

A large site exists, portions of which were used as firing ranges and other portions were used as bombing ranges and munitions target areas and all target areas were within the suspected impact areas. Nearly all target area locations are unknown with one exception where the general location was provided. A 100% geophysical survey is not feasible due to cost and accessibility issues.

It is necessary to derive a geophysical transect sampling scheme and apply post-survey analysis methods to 1) Detect all target areas of concern and 2) Delineate (establish a boundary around) each target area or cluster of target areas, 3) Estimate the anomaly density for each target area or target area cluster, and 4) Allow field analysts to determine if UXO are indeed present in high density areas.

3.3.2 Identify the Decisions

The first objective of conducting a geophysical survey would be to detect areas where UXO presence is highly suspect and distinguish these areas from background areas. Once detected, the next objective would be to define a boundary that would most likely encompass any UXO that might be present. Once a boundary is established, one would attempt to estimate anomaly density within the bounded area and decide whether 100% geophysical characterization would be necessary or another less than 100% transect sampling design would be most productive.

The key anomaly identification decisions are then:

- **Decision 1 (Detection):** Are there indications that a target area of concern (and therefore suspected UXO area) exists? (representative of suspected munitions used)
- **Decision 2 (Delineation)**: If so, what is the boundary of the target area and what is the average anomaly density estimate for the area?

3.3.3 Identify Inputs to the Decisions

Several factors are considered for each of the decisions, some of which come from the geophysical survey data and others from stakeholder input. The inputs to each decision are shown below.

Inputs for Decision 1 (Detection):
- Background anomaly density
- Anomalies and anomaly density along transects
- Density Threshold above which indicates a target area may exist (critical density)
- Geophysical instrument footprint and probability of detection
- Size and shape of target areas of concern
- Relative risks of making incorrect decision.
- Prior knowledge/information about target locations and munitions use (Conceptual Site Model).
- Cost of geophysical surveying.
- Areas where transects cannot be obtained
- Design reliability value at which the target boundary should be defined.

Inputs for Decision 2 (Delineation):

- Background density estimate
- Anomalies and anomaly density within a unit area
- Density threshold above which indicates a target area may exist (critical density)
- Risk of too narrowly defining the boundary vs. setting the boundary too wide.
- Anomaly locations from any additional transects within the suspected areas.
- Cost of geophysical surveying.
- Segment of transect over which average density is calculated.
- Spatial correlation model of the sampled intensity and/or indicator data
- Cost per anomaly for removal and/or detailed surveying

3.3.4 Define the Boundaries of the Study

The site contains five different areas with a combined area of over 300 sq. km and fixed by the site simulation contractor. The conceptual site model defines a different scenario for each of the five impact areas. The CSM suggests that known targets existed in these impact areas within the site, although exact locations of all targets are not known. The rest of the site has no known indications of target areas.

This study only addresses the target detection and delineation and does not address further/no further survey questions, discrimination, identification, or prioritization of anomalies. Known target and UXO locations were not revealed to PNNL/Sandia team until after the first two decisions above were made. It is assumed that the simulated site is representative of an actual site and dispersion patterns for each munition are representative of actual patterns.

Decisions 1 and 2 above will be applied separately to each suspected target area or target area cluster in each impact area.

3.3.5 Develop Decision Rules

Decision rules are in the form of if…then…else statements. The following decision rules and variations will be employed.

<u>Decision 1 (Detection)</u>: If the anomaly density within an area of size xxx is estimated to be greater than yyy then that area is identified as a suspect target area of interest. (xxx and yyy would be determined through analysis of the anomaly data)

<u>Decision 2 (Delineation):</u> If an area is identified as a suspect target area of interest and it is contiguous with other identified suspect target areas, those areas will be combined into a single bounded area and the boundary will completely enclose that area. If an area is identified as a suspect target area of interest but is isolated, then either a boundary will be developed that completely encloses the area, or additional transects will be requested to further explore the suspected target area and refine it's boundaries, or based on an evaluation of the surrounding anomaly patterns and the sensitivity to changes in the decision threshold, yyy, it may be removed from the suspect target area list.

If the probability of exceeding the density threshold is greater than www then a contour boundary will be drawn to include those areas where the probability of exceeding the threshold exceeds www.

The values of xxx, yyy, www, and zzz will be varied for these analyses to evaluate and demonstrate their effect on performance.

3.3.6 Specify Tolerable Limits on Decision Errors

There are two types of decision errors for each of the decisions as shown below.

Decision 1 Errors (Detection):

- Type I: Conclude that there is no target area of concern within an area when in fact there is UXO present in that area (False Negative error).
- Type II: Conclude that an area is a target area of concern when in fact there is no UXO present (False Positive error).

These error types are generalized to include conclusions of too few (Type I) or too many (Type II) target areas as they may be multiple target areas within a survey area.

The probability of making a type I decision error is dependent on the transect spacing, the size and shape of OE related fragment distribution, and the geophysical survey instrument detection rate. The probability of making a type II decision error could be affected by varying background anomaly densities, the difference between the background anomaly density and the anomaly density within a target area. For purposes of this demonstration, the error rates were controlled/evaluated by

- *Ensuring at least a aaa% chance of traversing and detecting an elliptical target area of bbb meters in width and ccc meters in length of un/known orientation that may be representative of the size and shape of a target area with fragment dispersion for various munitions.*

For this demonstration, different values of bbb, and ccc and how they affect the decision error rates were evaluated.

Decision 2 Errors (Delineation):

- Type I: The target boundary does not include all UXO associated with a particular target area (False Negative error). The probability of having a certain number of anomalies outside any defined target area will be quantified.
- Type II: The target boundary includes a much larger area than necessary, thereby increasing unnecessary characterization, digging, and cost (False Positive error).

The delineation decision is driven by the estimated anomaly density. A density decision threshold is selected and any areas above that threshold are enclosed within the boundary. For this demonstration, the methodology used and the effect of selecting various decision thresholds will be examined. The type I error was controlled to have no more than a 5% chance of a UXO falling outside the delineated areas (design reliability equals 95%). The type II error will be explored by comparing the acreage of the delineated areas for various decision thresholds used.

3.3.7 Optimize the Design

These tools optimize the transect design by providing the analyst with a balance between cost and identification. This demonstration shows how VSP tools can be used to maximize information from the minimum of transect surveys while enabling the researcher to know the power of the transect design and their level of certainty in the decision making process. Where power is defined as 1-β and β is the probability of a type II error as defined in the Decision 1 Errors (Detection) section above.

4. Performance Assessment

4.1 Performance Criteria

Assumptions that affect the transect sampling scheme (i.e., fragment distribution patterns, required traversing/detecting probabilities, and prior knowledge) were varied and multiple transect options were requested by PNNL/Sandia for each impact area. This provided an evaluation of the sensitivity of the results to assumptions and showed the tools available in VSP. Table 4 lists the performance criteria assessed in this report.

Performance Criteria	Description	Primary or Secondary
% UXO Within Boundary	The % of UXO that fall within the boundaries of the identified target areas.	Primary
% UXO Within Boundary if Target Area has a Sufficient Density	The % of UXO that fall within the boundaries of the identified target areas with a true target area density of greater than 6 anomalies per acre above background.	Primary
% of Target Areas Identified	The % of all true target area locations that were identified and encompassed within the boundaries.	Primary
% of Target Areas Identified if Target Area has a Sufficient Density	The % of all true target area locations with a target area density greater than 6 anomalies per acre above background that were identified and encompassed within the boundaries	Primary
Target Area Identification	The accurate distinction between target areas and high density non-OE related areas.	Secondary
Land Area Covered	% of land area traversed by geophysical transects. Should be small relative to entire land area.	Primary
Accurate Anomaly Density Estimation	Accurate estimate of anomaly density and number of anomalies within each suspected target area.	Primary
Unnecessary Inclusion of Land Mass Inside Bounded Areas.	Boundaries around the suspected target areas are sufficiently accurate to minimize the future dig area to include the UXO.	Secondary

Table 4: Performance criteria for simulation demonstration

4.2 Performance Confirmation Methods

PNNL and Sandia evaluated the site characteristics and historical information to recommend several sets of transect designs. Mitretek processed the transects and provided the anomaly locations found along the requested transects. The statistical analysis tools developed by PNNL and Sandia were used to identify suspected target areas. Additional transects were requested to better define the anomaly characteristics within some of the suspected impact areas. Mitretek supplied an additional list of anomaly locations based on the additional transect requests and the estimates for the target area locations and boundary delineations were finalized. Estimates of the number/density of anomalies in each target area and boundaries of the target areas were derived and provided to Mitretek. Finally, Mitretek provided the actual simulated data showing the location of all targets and UXO and the simulated background levels for each area. An evaluation of the performance of the statistical methods per the criteria outlined above is described in the following sections.

4.2.1 Process of Transect Design and Analysis

The process of target area identification can follow a four stage process – Design, Detection, Iteration, and Delineation. Each stage is important for developing the correct conclusions about the potential target areas in wide area assessment. The original demonstration plan proposed a fifth step of dig identification. This step was removed from demonstration by ESTCP and Mitretek did not provide data in a manner that this step could be performed.

A proper transect design must be created to attain the desired results. At this stage all prior information about the site in an archive search report (ASR) or conceptual site model (CSM) is used to decide on the different parameters and assumptions necessary for the transect design. Figure 2 shows the tabs within the VSP software that allow the user to input the required parameters and assumptions. A target area size and shape are defined based on the munition used in the site and the dispersion pattern of the used munitions, as shown in Figure 8. The user defines the transect width, the orientation of the target to transect design, and chooses a transect pattern---square, parallel, or rectangular. The transect spacing is dependent upon target area assumptions and the required probability of traversing a target area.

Target Identification begins after the data have been gathered from the proposed transect designs. The target identification algorithm, currently in VSP, implements a circular window to calculate the density of anomalies within a certain distance from the center of the window. This window, centered on a transect, systematically moves along each transect of the site and flags an area as high density when the defined moving window has more anomalies than expected for background anomalies alone. Because there is often no prior estimate of background anomalies, VSP provides the capability of examining the distribution of densities based on a user defined window diameter. The user can then determine an optimum critical value or background density based on this window size. With the optimum window size and appropriate background density determined, potential target areas are identified. Figures 6 and 7 show the VSP tabs that perform the target area identification functions in VSP. At this stage additional transects may be requested to better identify potential target areas. This process is iterative and additional transect requests could occur depending on the uncertainties of the flagged areas and the time and finances allocated to the remediation. After all of the desired anomaly data based on the requested transects are obtained, a final target area detection routine is run and all potential target areas are identified.

Finally, the boundaries of the identified (flagged) target areas are delineated. VSP will provide two methods to identify the perimeter of potential target areas. Currently VSP allows the user to visualize the size of the flagged target areas and then manually create a boundary (created as a convex hull of straight-line segments) that surrounds the flagged areas of concern. VSP is in the final stages of integrating SNL's geostatistical methodology to estimate the density and perimeter of a target area. The geostatistical approach supports two different means of delineating the target boundary: 1) a map is created defining the probability of being within a target area across the entire site. Mapping the probability allows the decision makers to select the probability with which they are most comfortable. For example, if all locations with a 5 percent or greater chance of being within a target area are delineated as target areas (95 percent reliability) then any location outside of this boundary has a less than 5 percent chance of actually being a target area – or the Type I error is controlled to be less than 5 percent at any location. 2) a map of anomaly density is created for the entire site and locations where the estimated density exceeds the critical density are delineated as targets. This second approach does not allow for a direct control of decision errors, but provides a more intuitive understanding of the target boundary as it is based directly on anomaly density estimates.

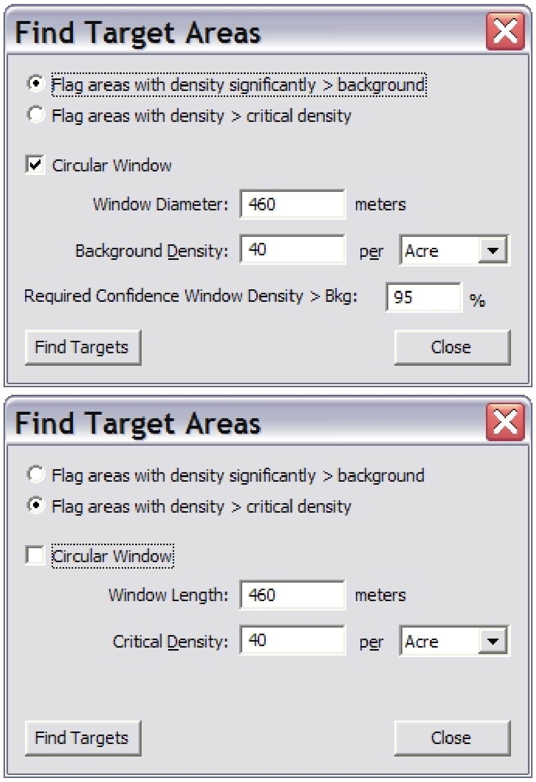


Figure 6. VSP Dialog Box On Target Area Detection

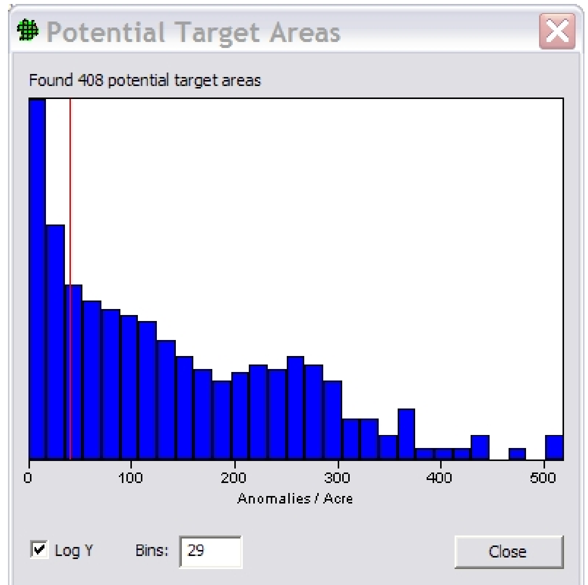


Figure 7. VSP graph which shows the distribution of anomaly densities based on a defined window size.

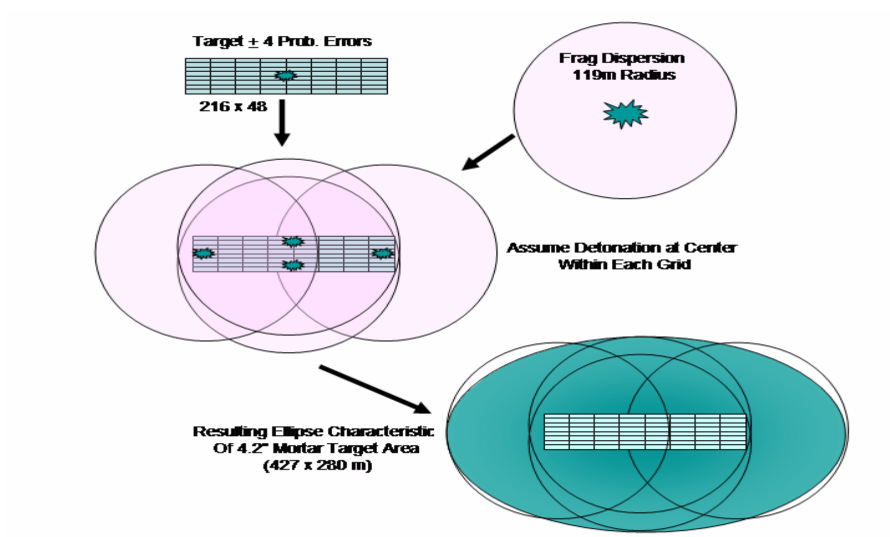


Figure 8: Diagram of Derivation of Target Area Size/Shape of Concern

4.3 Data Analysis, Interpretation and Evaluation

Mitretek provided SimRangE Scenario 4, which contained the 5 impact areas shown in Figure 9. It was assumed that 4.2” mortars and 155mm projectiles were the main munitions used on the site. One larger impact area was used for aerial bomb training of live and smoke filled bombs (M30 100lb, M31 300lb, M43 500lb, M34 2000lb bombs) and one smaller area was used for small arms training. PNNL/Sandia developed multiple transect designs for 4 of the 5 impact areas with ARA-1 only having one transect design created. The different transect designs for the same impact areas were meant to provide an opportunity to check sensitivity of decision results to target area assumptions.

Figure 9: Complete SimRangeE Scenario with the five simulated impact areas

This simulation contained some targets areas that had very low anomaly densities. In ARA-2B there were 5 targets that had a density above background of less than 1 anomaly per acre. A total of 15 of the 58 targets had a density above background of less than 6 anomalies per acre. Tables 5 and 6 summarize by scenario the number of targets that had a density less than 6 anomalies per acre above background or greater than 6 anomalies per acre above background respectively.

Impact Area	Transect Spacing	Percent of Site Covered with Transects	Total Number of Target Areas	Total Number of UXO
ARA-2B	345m	0.58%	8	19
ARA-2B	282m	0.71%	8	19
ARA-2A	344m	0.60%	2	38
ARA-2A	298m	0.33%	2	38
ARA-1	344m	0.66%	5	73
BGR-1	483x961m	1.20%	0	0
BGR-1	232m	0.86%	0	0

Table 5: Summary of simulation for each scenario based on targets areas with densities less than 6 anomalies per acre above background

Impact Area	Transect Spacing	Percent of Site Covered with Transects	Total Number of Target Areas	Total Number of UXO
ARA-2B	345m	0.58%	9	253
ARA-2B	282m	0.71%	9	253
ARA-2A	344m	0.60%	3	175
ARA-2A	298m	0.33%	3	175
ARA-1	344m	0.66%	7	110
BGR-1	483x961m	1.20%	24	92049
BGR-1	232m	0.86%	24	92049

Table 6: Summary of simulation for each scenario based on target areas with a density above background of 6 anomalies per acre

4.3.1 Artillery Range Area 1 (ARA-1)

Artillery Range Area 1 covered 21,000 acres and had primary targets towards the center of the range. Each of the targets was fired upon from multiple staging sites by 4.2" mortars and 155mm projectiles. The PNNL/Sandia team was also provided the location and area of "observed" terrain scaring. The observed terrain scaring was located at the center of the ARA-1 site and had a diameter of approximately 2 km. As discussed below, this information was used to investigate the incorporation of prior information into geostatistical estimation process.

4.3.1.1 ARA-1 Transect Design

One transect design was developed for this impact area based on the potential 427 by 280 m target area size of 4.2" mortars, as shown in Figure 8. Three north-south transects were requested, with the original east-west transects, that would have a high likelihood of traversing the potential central target areas. The 2 m wide east-west transects, shown in Figure 10, were 344 m apart, covered 0.66% of the ARA-1 impact area and had a 95% probability of traversing the target area of interest. Based on the results from the preliminary target identification no additional transects were requested to better discriminate potential areas.

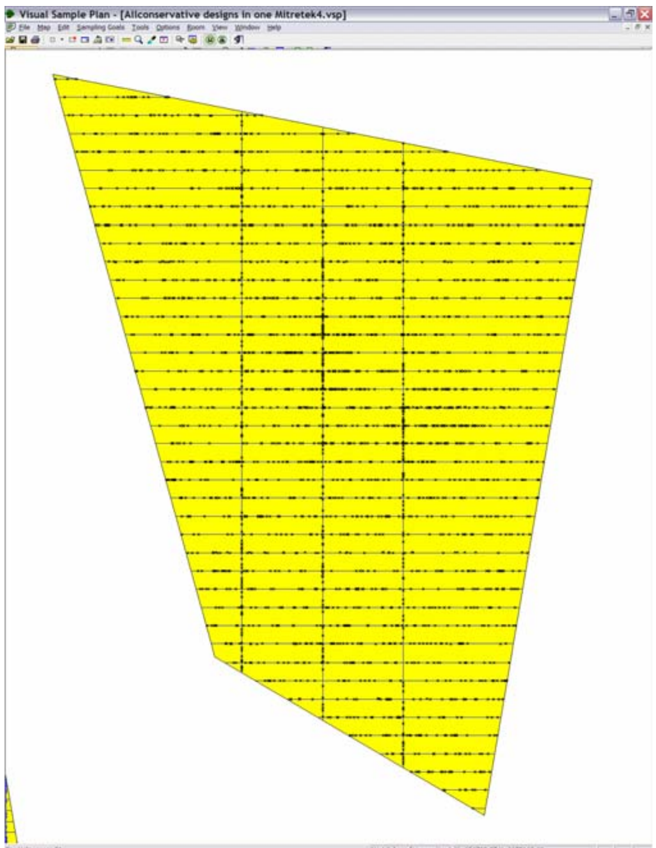


Figure 10: ARA-1 transect design with identified anomalies

4.3.1.2 ARA-1 Target Area Identification Results

Two potential target areas were identified in this impact area. These target areas were derived using both the perimeter estimates from the VSP flagging routine and SNL's geostatistical perimeter estimation. Figure 11 shows the final perimeter estimates for ARA-1 created with the VSP flagging routine along with the actual maximum size target areas based on the simulation results from Mitretek and Figure 12 shows the perimeter estimates with the UXO plotted on the target areas. The actual simulated targets did have some overlap which would increase the density per acre in the overlapping area. Except for one target, all low density target areas were the farthest away from the other target areas. Each target area is color coded by its density above background (18.21 anomalies per acre) as calculated by dividing the total number of simulated fragments and UXO by the maximum perimeter of each simulated target area. For any target with a density of 6 anomalies per acre or higher above background, the target area identification tools contained 100% of the UXO. This site contained 5 target areas with an anomaly density similar to background and the lowest density area did not contain any UXO. For the overall site 77% of the UXO was contained within the PNNL/Sandia delineated target areas. These results are summarized in Table 7.

Density of Target Areas above background	Transect Spacing	Percent of Site Covered with Transects	Total Number of Target Areas	Total Number of UXO	Number of Target Areas Identified	Number of UXO Contained	Percent of Target Areas Identified	Percent of UXO Contained
>6	344m	0.66%	7	110	7	110	100.00%	100.00%
<6	344m	0.66%	5	73	1	31	20.00%	42.47%

Table 7: Target identification performance for ARA-1.

Many combinations were examined between window size and critical density. PNNL used a 900 m diameter circular window with a critical density of 34 anomalies per acre as the analysis values to identify the finalized target areas.

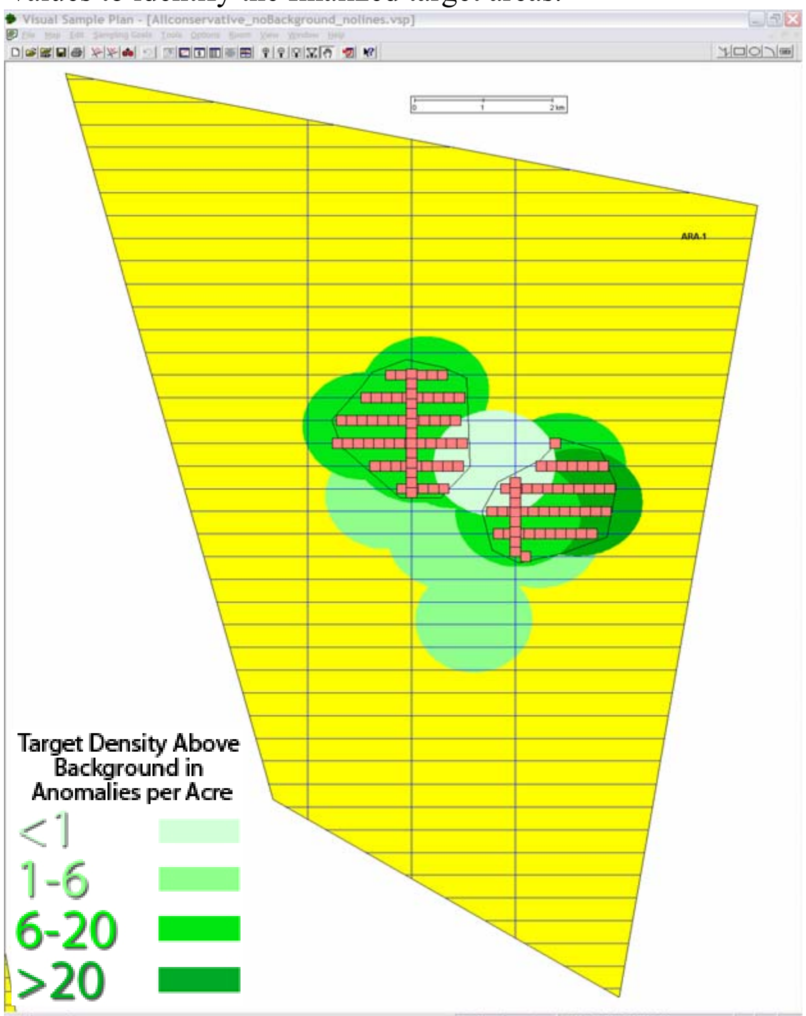


Figure 11: Results of ARA-1 with flagged areas, perimeter delineation and target area density and size for each target.

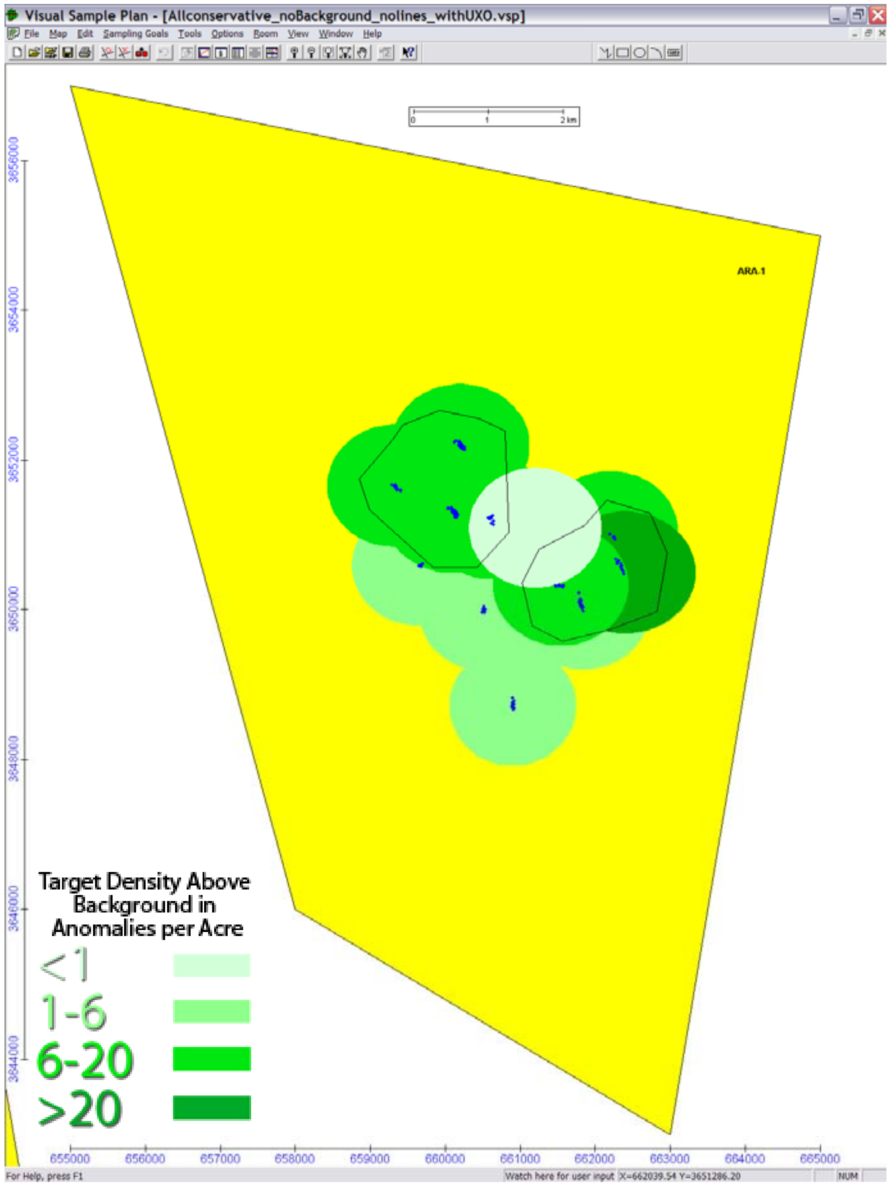


Figure 12: UXO coordinates plotted on ARA-1 map with perimeter delineation, target area size and density for each target.

Sandia's processing techniques differed from PNNL's primarily in that different upscaling techniques were used. SNL's approach was to average the anomaly counts within a rectangular moving window working within a grid-based framework. This technique focused on a single transect during the averaging process. For all of the simulated ranges discussed in this report, a rectangular averaging window 350 m in length with a width equal to the transect sample width (typically 2 m) was used. This averaging window was centered at the averaging location and oriented parallel to the sampling transect. These differences in upscaling techniques often lead to different critical density levels for target area delineation resulting from the SNL and PNNL averaging techniques. For ARA-1 SNL used a critical density level of 65 anomalies per acre for target delineation.

To model the spatial variability of the transect data, variograms were developed for each of the kriging estimates presented here. Variograms model how the variance between data points changes as the spatial distance between any two points increases. Typically the variance increases as the distance between points increases. Figure 13 presents the indicator and standard variograms developed using the transect data from ARA-1. The points in this figure represent the variance values computed at specific lag distances. The solid lines represent the analytic models fit to the data points. It is these model curves that are used during the kriging procedures. The parameters describing these curves are provided in Appendix A.

Figure 14 shows the indicator kriging probability levels for ARA-1 using an indicator kriging threshold of 65 anomalies per acre. Only areas with a probability of 0.05 or greater of being above the 65 anomalies per acre threshold are indicated by color-filled contours. These areas were included as part of the information used in determining the final target boundaries. The two indicated areas falling outside of the PNNL/SNL final target boundaries were considered too small to be actual targets based on the available range use information, and so were not included in the final target delineation. This decision was confirmed as proper after the full simulated range data were available.

Figure 15 shows magnetic anomaly density maps for both the kriging estimates and the original site data for ARA-1. The kriging estimate was created using 50 m square grid cell spacing. The actual anomaly density map was created using all anomaly information for the range (UXO, fragments, background clutter, etc.) as provided by Mitretek and was generated by averaging the anomalies using the same grid framework (50 m cells) as used in the kriging estimates. All density values are presented as anomalies per acre.

Comparison of the estimated and actual anomaly density maps shows that, using only limited transect information, the major features of the magnetic anomaly density distribution of the simulated site are well represented in the kriged estimates. The notable exceptions are the relatively small high-density area found at the southern end of the simulated impact area which is not represented in the kriged estimate, and several sporadic areas in the kriged estimates which are above the true density values. These typically occur outside of the simulated impact area within the field of background clutter.

Figures 16 and 17 show comparison box and whisker plots for each of the target areas and for the entire ARA-1 range. The data compared are the grid cell averaged true magnetic anomaly data and the estimated kriging values. These figures show that the interquartile range and mean of the original anomaly data set is well represented by the kriged estimates, but the range of the estimated values is smaller. This reduction in the overall range of values is due to the smoothing nature of the kriging estimator and the fact that the extreme high and low density values of the true data are not necessarily intersected by sampling transects.

Table 8 presents a comparison of some basic statistics from the original and estimated anomaly data sets. It shows that the mean of the estimated density for each of the delineated target areas are all within approximately 15% of the actual mean, and the mean for the entire site is within 5% of the actual.

The ARA-1 range was also used as an example of including prior information into the geostatistical estimation techniques. As used here, prior information is defined as information independent of the transect data which may aid in target delineation. Typically this information is anecdotal or 'soft' in nature and may be derived from archival search reports (ASR's) and/or aerial photography obtained during the history of the site operation.

As an example of prior information, simulated range ARA-1 is reported to have surface scarring centered at XY location 60,000/50,000, with a diameter of approximately 2,000 meters. To test the consistency of this prior information against actual sample transects, a model representing the prior information (Figure 18) was developed and the differences between the model and the transect data were computed. These residuals were then used to krig residual estimates for the entire ARA-1 range. The kriged residuals were then added to the model of prior information to obtain the final estimate of anomaly densities.

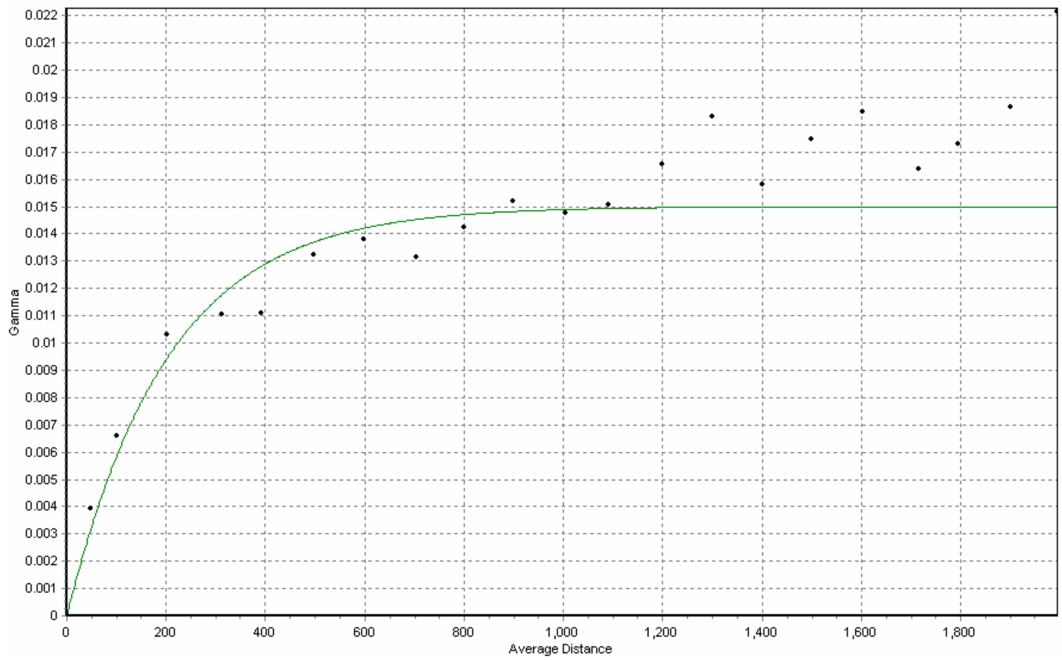
The prior information was modeled using a bivariate Gaussian distribution with a maximum value set equal to that observed in the processed transect data (80.9 anomalies per acre) and a standard deviation equal to the range of the variogram for the transect data (900 m). The background density was set to the lower quartile of the transect data.

As a test of including prior information with only very limited transect data, only six transects were used in the analysis. These were divided into an equal number of north-south and east-west transects which intersected the area of interest indicated by the prior information. The locations of theses six transects and the results from kriging with only these six transects are shown in Figure 19. Figure 20 shows the anomaly density estimate resulting from the inclusion of the prior information along with the six transects. Comparing Figures 19 and 20 shows little difference between the distributions of anomaly density estimates. This indicates that the prior information is inconsistent with the field-sampled transect data and hence is likely incorrect. This is confirmed by examining the kriged estimates developed from using more comprehensive transect data. Figure 21 shows kriged estimates of magnetic anomaly density developed using 41 sample transects. As indicated by this figure, there is no large, high-density feature located at the location surmised by the prior information. This confirms that the original prior information was in someway biased or incorrect.

To demonstrate the inclusion of prior information which is consistent with the sample transect data, an additional prior model was constructed. This model was developed in a similar manner as before using the maximum observed densities along the transects and the anomaly density variogram ranges as the standard deviation of the bivariate Gaussian model, but for this analysis, the bivariate Gaussian feature was centered over high density features observed in the kriging estimates constructed from the comprehensive (41 transect) data. Two of the high-density features observed in Figure 21 were considered in the development of this example of prior information. Figure 22 shows the model of prior information resulting from this process.

Figure 23 shows the result of including prior information which is consistent with the transect data. The kriging estimates shown in this figure were developed using the new prior information model and the original six transects. As shown in the figure, areas with high anomaly density initially indicated by the transect data are expanded by the inclusion of the prior information. This expansion of the high density areas results in an estimated anomaly distribution which more closely resembles that developed from the 41 sample transects.

The examples of including prior information discussed above show how this process can be used to help establish the reliability of the prior information, and, when the prior information is consistent with field observations, use the prior information to help refine estimates developed from transect data. A significant advantage of this approach is that the “hard” data coming from the transects always overrides the “soft” prior information, and therefore, if the two data sets are inconsistent, the final estimate will be more consistent with the, presumably, more reliable transect data.



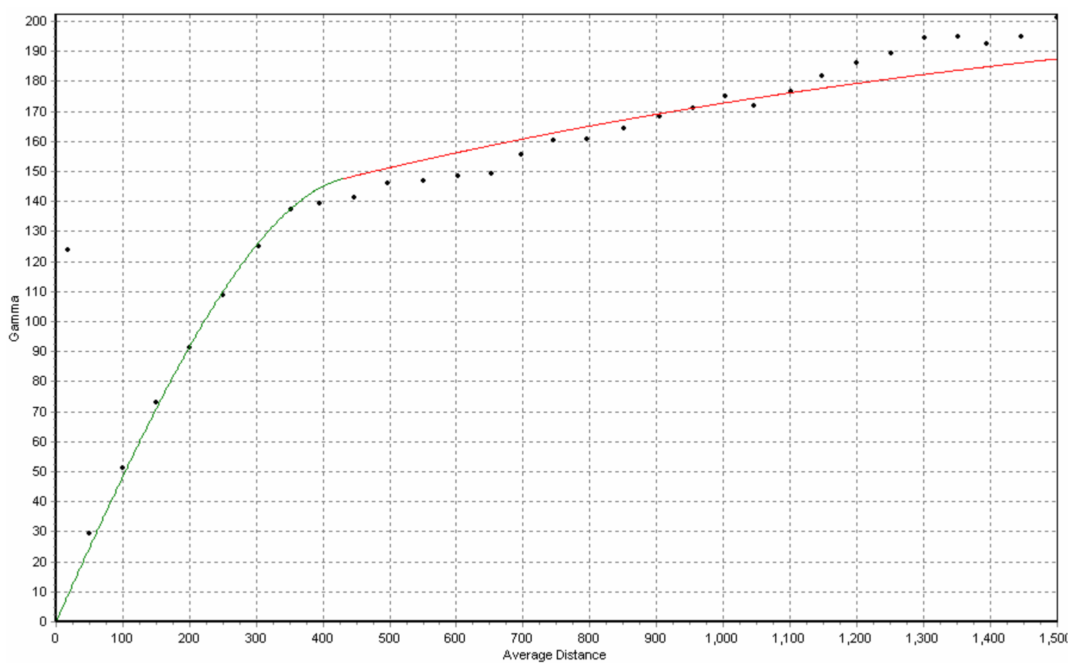


Figure 13: Variograms for indicator variable using a threshold of 65 anomalies per acre (top plot) and anomaly per acre values (lower plot) for ARA-1. Points represent values computed from transect data; solid lines represent models fit to data points. See Appendix A for a listing of values and explanation of the parameters used in the variogram models.

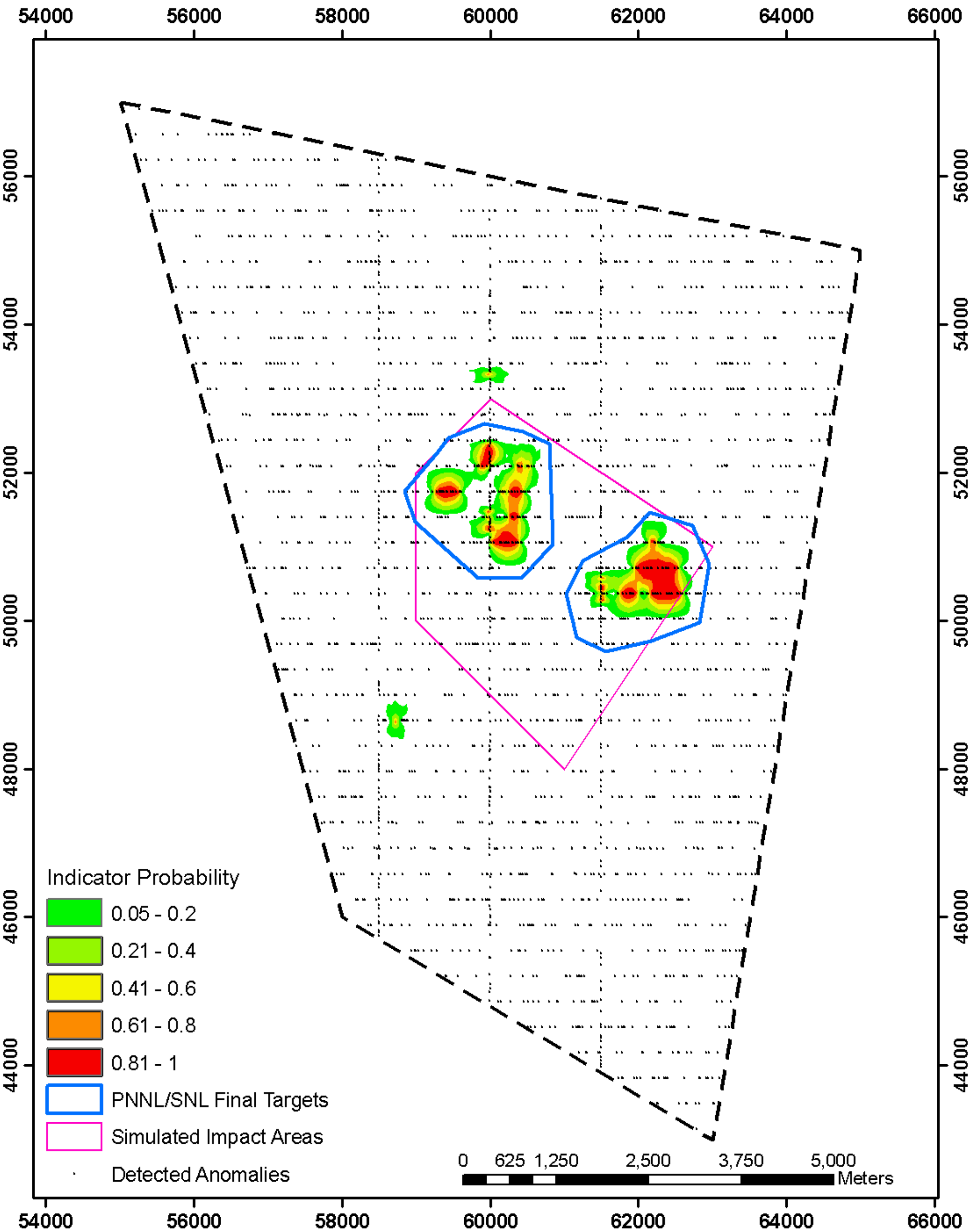


Figure 14: ARA-1 indicator kriging probability levels for an indicator threshold level of 65 anomalies per acre.

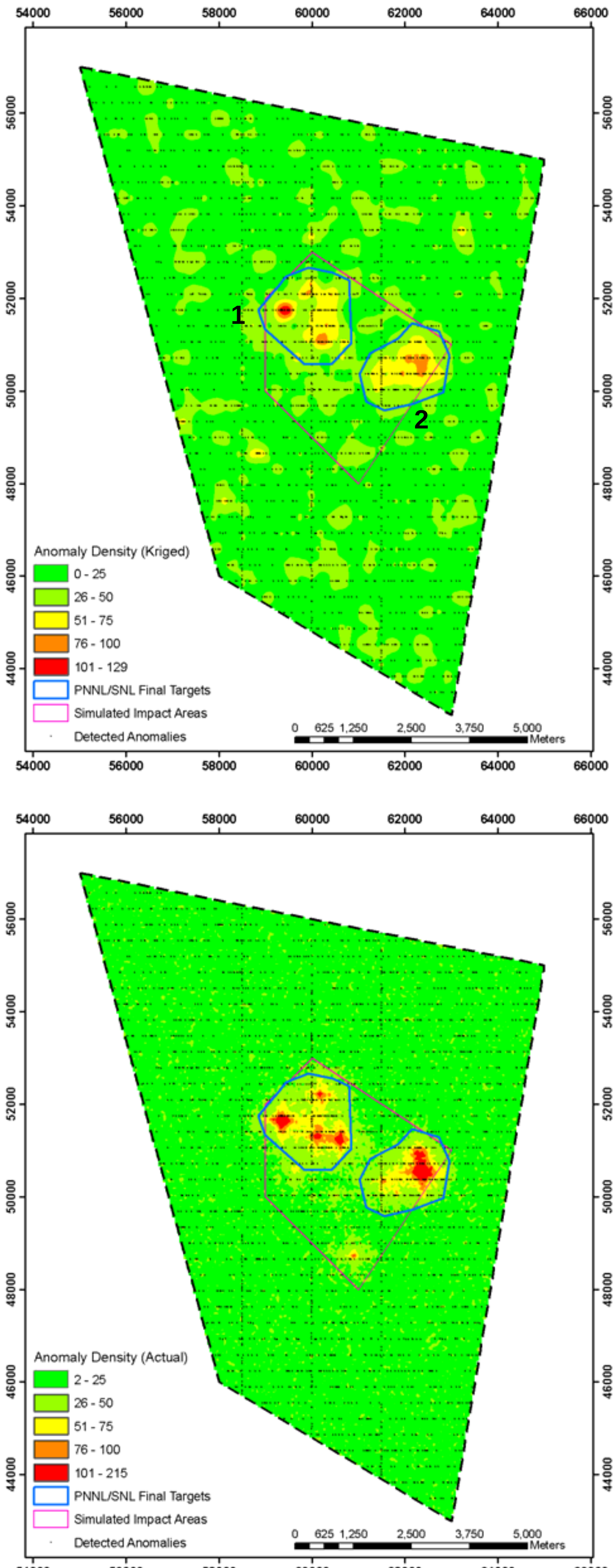
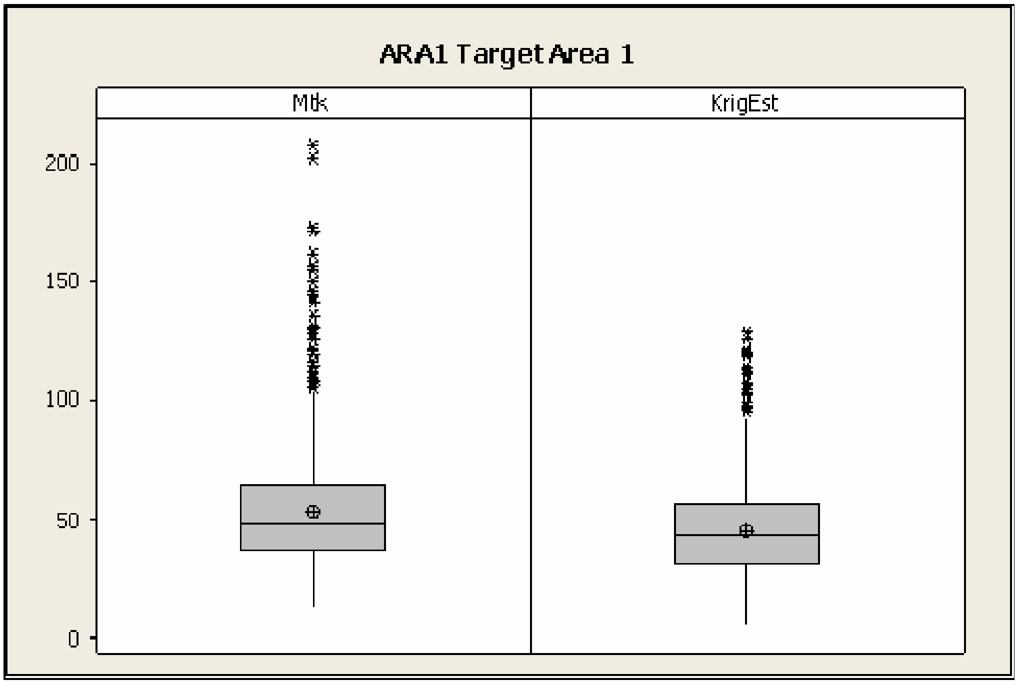


Figure 15: Magnetic anomaly density (anomalies per acre) maps for ARA-1. Upper figure shows kriged estimate with target number, lower figure shows actual distribution.



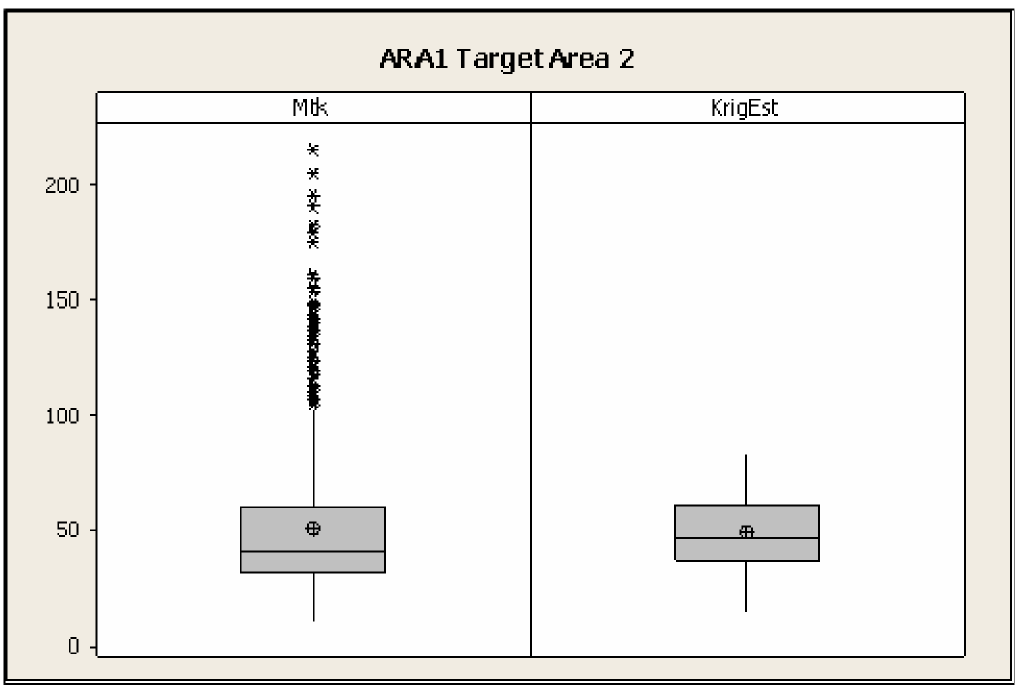


Figure 16: Box and whisker plots comparing Mitretek range anomaly densities (Mtk) and kriging estimated densities (KrigEst) for individual target areas. Boxes represent interquartile range with median shown by horizontal line. Vertical lines show largest value within upper limit (Q3+1.5(Q3-Q1) and smallest value within lower limit (Q1-1.5(Q3-Q1) with outliers beyond this range shown by asterisks. Mean is shown by circle with cross.

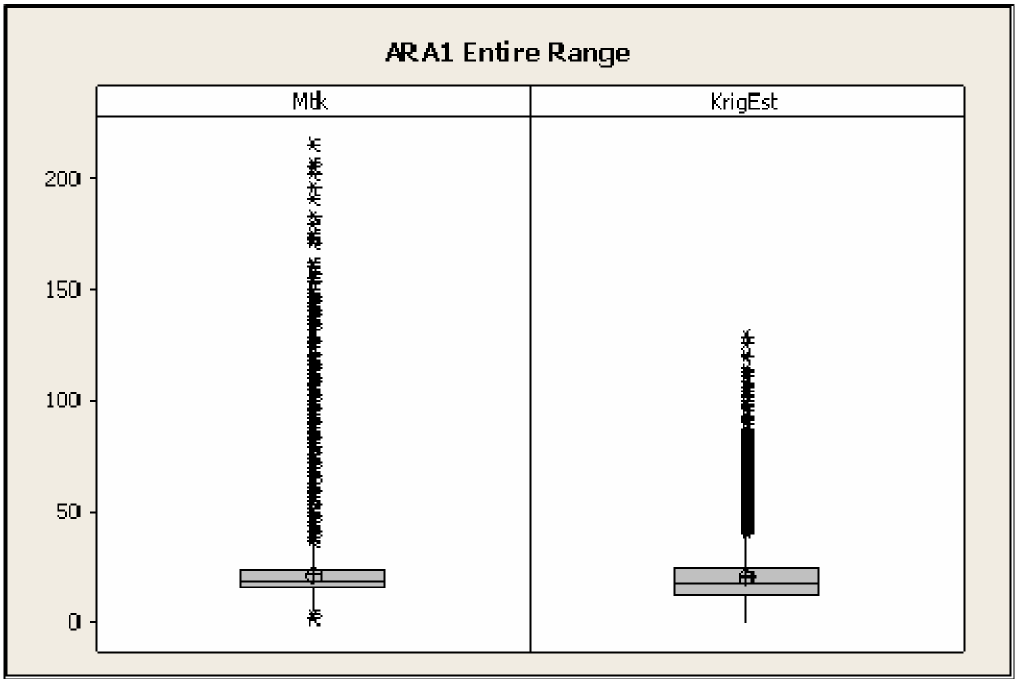


Figure 17: Box and whisker plots comparing Mitretek range anomaly densities (Mtk) and kriging estimated densities (KrigEst) for entire ARA1 range area. Boxes represent interquartile range with median shown by horizontal line. Vertical lines show largest value within upper limit (Q3+1.5(Q3-Q1) and smallest value within lower limit (Q1-1.5(Q3-Q1) with outliers beyond this range shown by asterisks. Mean is shown by circle with cross.

Area	Source	Mean	Mean Diff.	Std Dev	Min	Max
Target 1	Mtk	53.4	-14.8%	23.3	13.0	207.2
	KrigEst	45.5		18.6	6.1	129.0
Target 2	Mtk	50.8	-2.8%	29.3	11.3	215.3
	KrigEst	49.4		15.4	15.8	84.3
Entire Range	Mtk	21.6	-4.6%	12.2	1.6	215.3
	KrigEst	20.6		11.5	0	129.0

Table 8: Comparison of estimated (KrigEst) and actual (Mtk) magnetic anomaly densities for ARA-1 range.

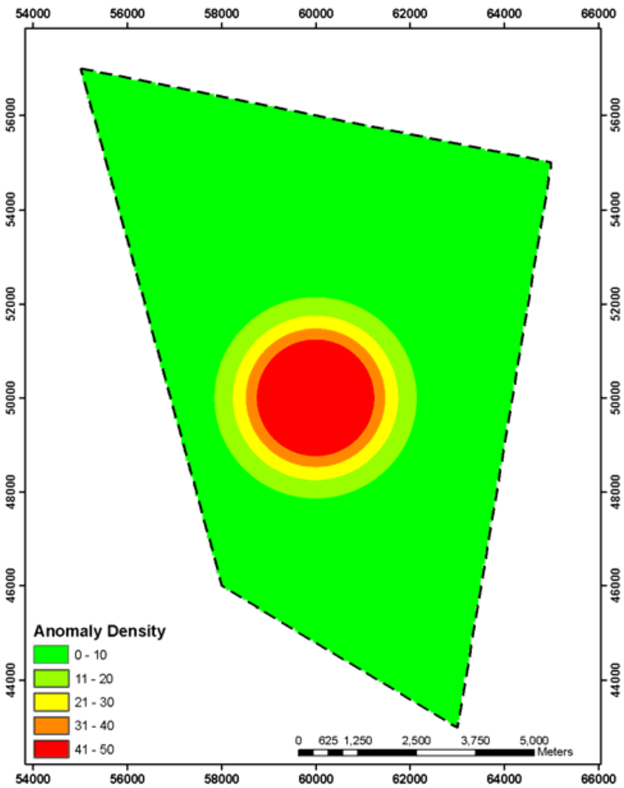


Figure 18: Model representing original prior information. Data represent hypothetical anomaly densities in anomalies per acre.

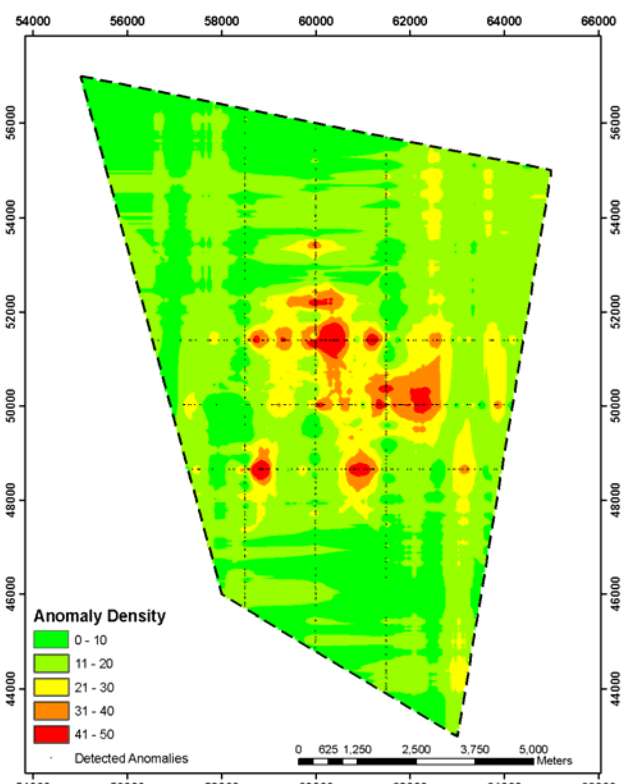


Figure 19: Magnetic anomaly density estimates (anomalies per acre) for ARA-1 developed using only six transects and no prior information.

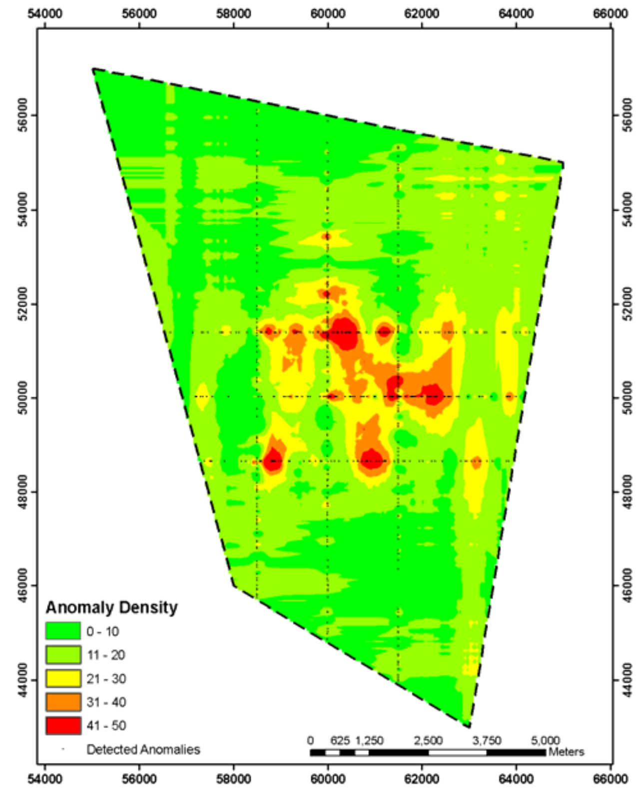


Figure 20: Magnetic anomaly density estimates (anomalies per acre) for ARA-1 developed using original prior information model and six sample transects.

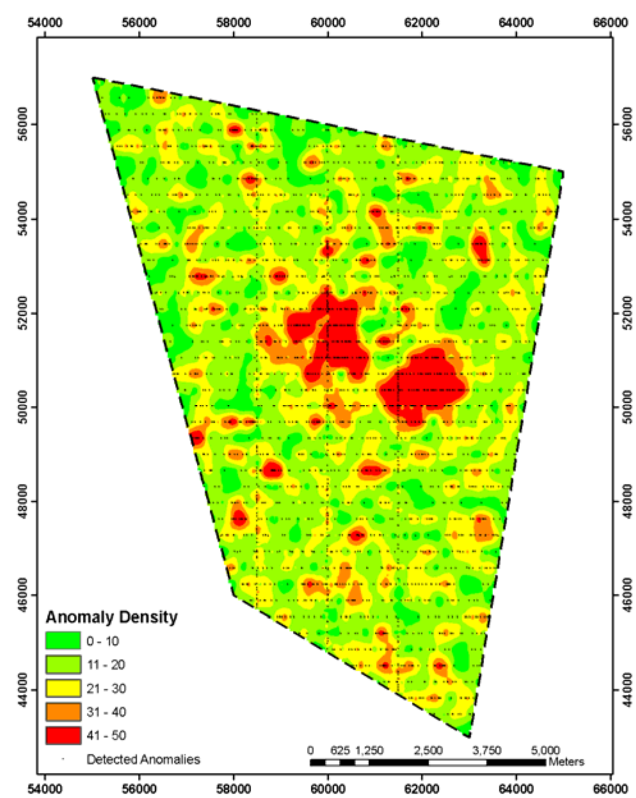


Figure 21: Magnetic anomaly density estimates (anomalies per acre) for ARA-1 developed using 41 sample transects.

Figure 22: Model representing revised, two-target prior information. Data represent hypothetical anomaly densities in anomalies per acre.

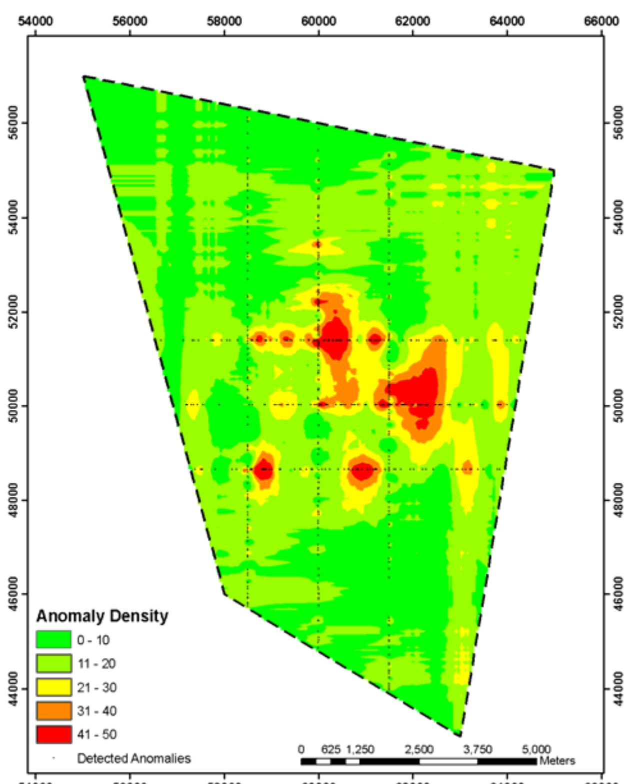


Figure 23: Magnetic anomaly density estimates (anomalies per acre) for ARA-1 developed using revised, two-target prior information model and six sample transects. Compare to Figure 20.

4.3.2 Artillery Range Area 2A (ARA-2A)

Artillery Range Area 2A is smaller than ARA-1 at 19,000 acres, but contained the same possible munition as ARA-1. ARA-2A was used less than the other impact areas and no information about the location or number of target areas in this impact area was available.

4.3.2.1 ARA-2A Transect Design

Two transect designs were developed for ARA-2A based on the potential 427 m long by 280 m wide elliptical target area. One transect design, shown in Figure 24, had 2 m transects spaced 344 m apart and the second design (Figure 25) had 1 m transects spaced 298 m apart The tighter transect design was based on the assumption that lower use sites could have a smaller range and deflection probability for the munitions of interest. Although the transect spacing was set based on a probable target area size and a desired probability of traversal (95%), the width of the transects for each design was varied to examine detection sensitivity to transect width. Based on the preliminary results additional transects were requested for the 2m transect design (the east-west transects shown in Figure 24). Each area with additional transects requested resulted in an identified target area. The 1 m transect design covered 0.33% of ARA-2A and the 2 m transect design covered 0.59% of the impact area.

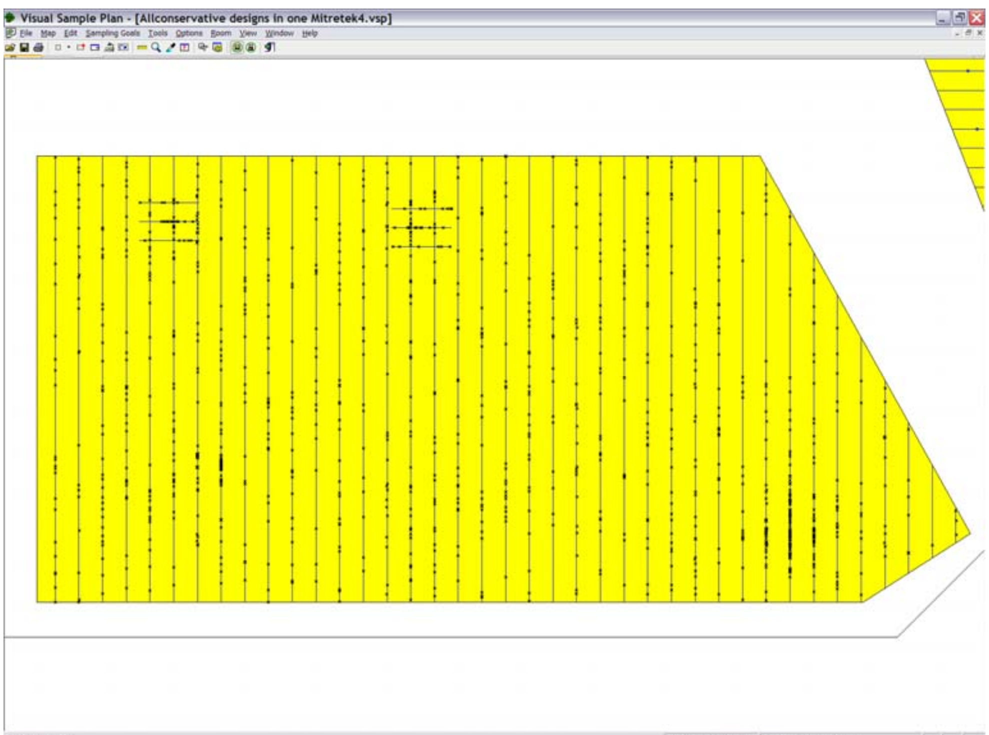


Figure 24: Final requested transect design for 2-m wide transects spaced 344 m apart with anomaly locations for ARA-2A.

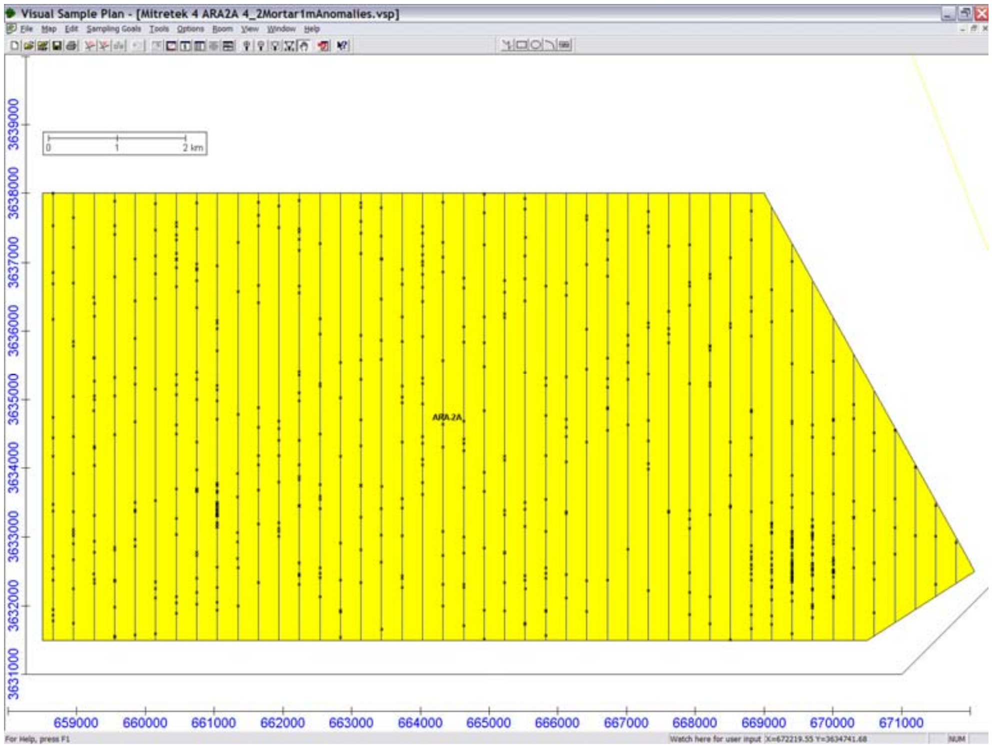


Figure 25: 298 m spaced 1 m wide transect design for ARA-2A with anomalies

4.3.2.2 ARA-2A Target Area Identification Results

This impact area had a background level of 10.12 anomalies per acre, 5 simulated target areas, and 1 target area based on data from the clean up at Ft. Ritchie. This Ft. Ritchie data was separated into four different regions labeled as sectors in Figure 26. These four sectors (1, 3, 4, 6) located next to each other, should really be analyzed as two different target areas. **Sector 6 was in an open area and only contained UXO -- it did not contain any fragment locations from the exploded ordinance.** Sectors 1, 3, and 4 contained fragments and UXO but had large un-sampled areas due to buildings and parking lots that were not identified in the ARA-2A map, area summary, or as a result of the transect requests. Some of the irregularities associated with the Fort Ritchie data used here are discussed further in Appendix B at the end of this report. Because of the complexities of the Ft. Ritchie data, these results are reported separately from the simulated target area results in Table 9. The Ft. Ritchie results are listed in Table 10.

Density of Target Areas above background	Transect Spacing	Percent of Site Covered with Transects	Total Number of Target Areas	Total Number of UXO	Number of Target Areas Identified	Number of UXO Contained	Percent of Target Areas Identified	Percent of UXO Contained
>6	344m	0.006	3	175	3	175	1	1
>6	298m	0.0033	3	175	3	175	1	1
<6	344m	0.006	2	38	1	27	0.5	0.710526
<6	298m	0.0033	2	38	0	0	0	0

Table 9: Target area identification results for ARA-2A without Ft. Ritchie data

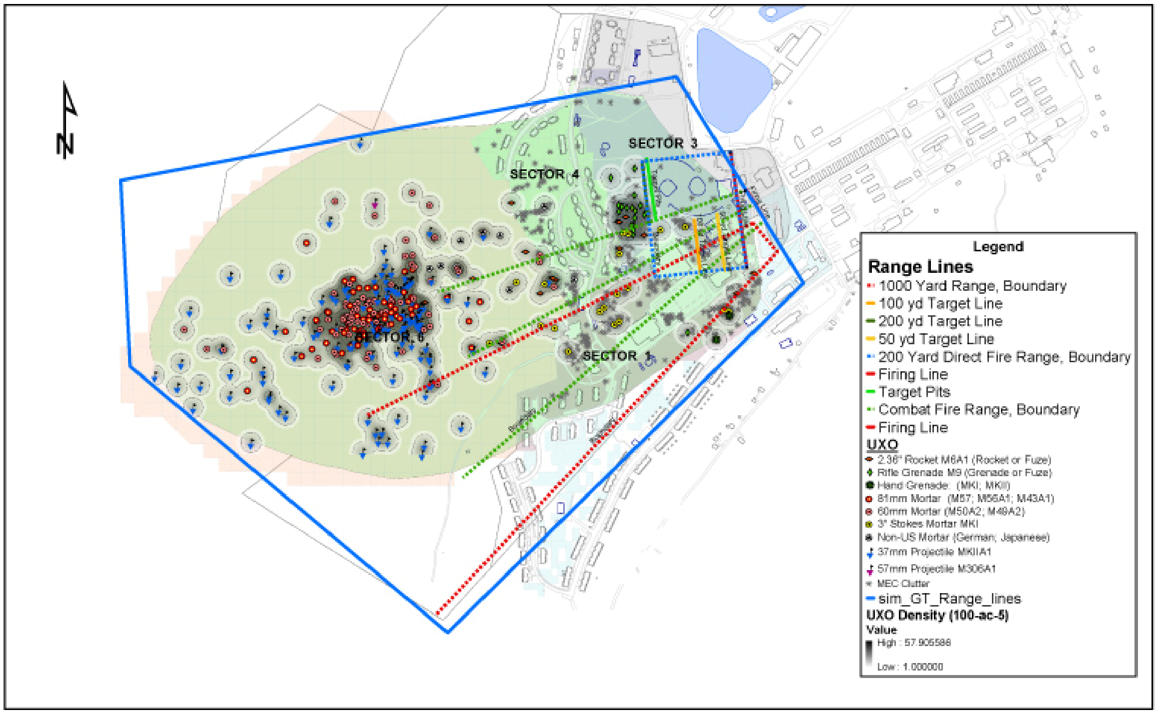


Figure 26: Map of Ft. Ritchie data supplied to PNNL/Sandia by Mitretek.

Scenario	Sector	UXO Present	Fragments Present	Sector Size (Acres)	Sector Area Density above background	Fragments Around UXO	Number UXO Identified	Sector Identified	Percent UXO Identified
344 m	1,3,4	45	9100	68	135	Y	45	Y	100%
344 m	6	310	134	125	3.54	N	304	Y	98%
298 m	1,3,4	45	9100	68	135	Y	39	Y	87%
298 m	6	310	134	125	3.54	N	16	N	5%

Table 10: Ft. Ritchie data separated by sectors with Fragments around UXO

PNNL identified the final flagged target areas by using a window diameter of 650 m with a background density of 25 anomalies per acre and a 550 m diameter window with a background density of 37 anomalies per acre for the 344 m and 298 m transect designs respectively. Sandia identified their targets using a rectangular averaging window 350 m in length with a width equal to the transect sample width. This width was 1 m and 2 m for the 298 m and 344 m transect scenarios respectively. The final critical density levels determined by SNL for the ARA-2A range were 46 anomalies per acre for the 298 m transect spacing, and 45 anomalies per acre for the 344 m spaced transects.

In each design all the targets with target density of 6 anomalies per acre or more above background were identified. The 2 m wide transects that were spaced 344 m apart did identify one of the targets that was about 5 anomalies per acre above background. Figures 27 and 29 have the simulated values displayed with the perimeter estimates for the 344 m spaced transect design. Figures 28 and 30 are similar graphs with the target area perimeters for the 1 m transects spaced 298 m apart.

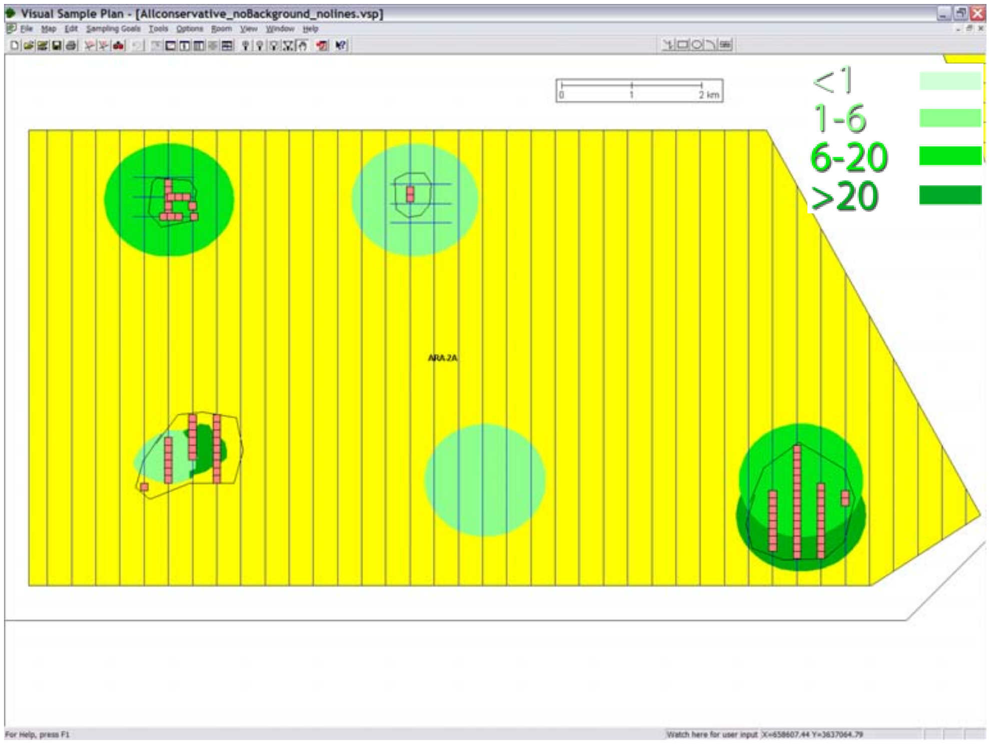


Figure 27: ARA-2A with flagging, final target area perimeters (black lines), and actual target areas colored by density for the 344 m transect spacing

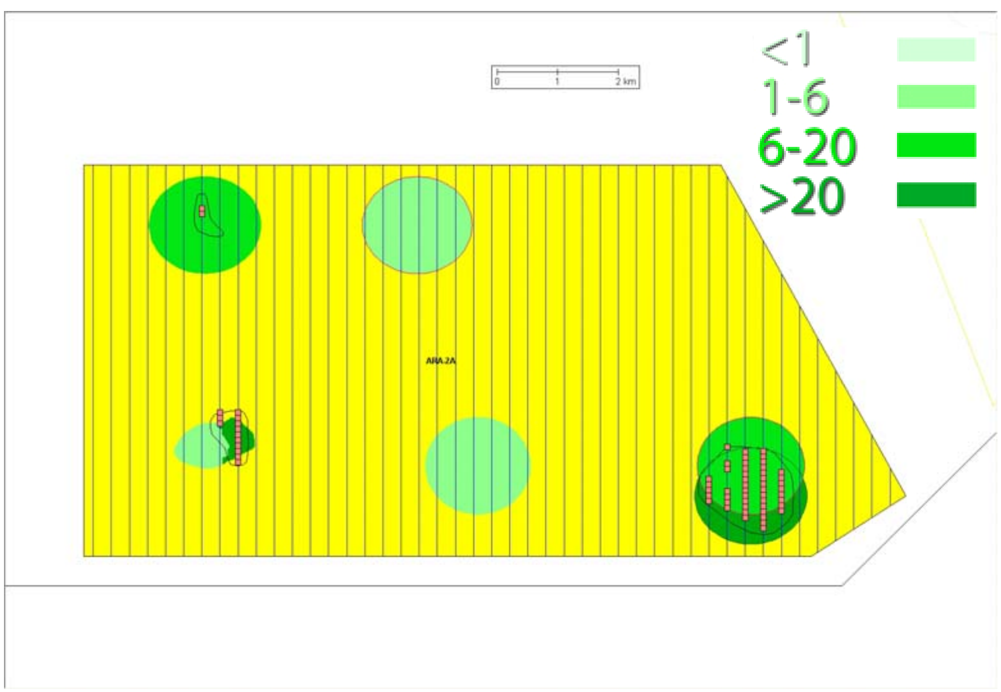


Figure 28: ARA-2A with flagging, final target area perimeters (black line), and actual target areas colored by density for the 298 m transect spacing

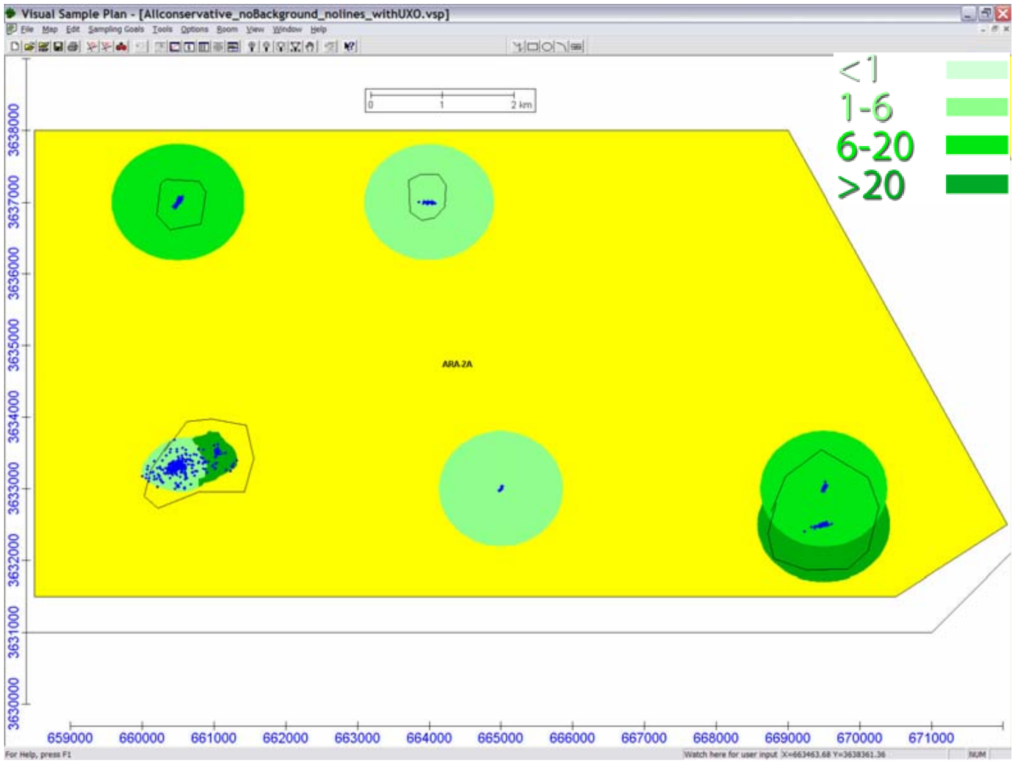


Figure 29: UXO coordinates plotted on ARA-2A simulated target map with perimeter delineation based (black lines) on the 344 m spaced transect design.

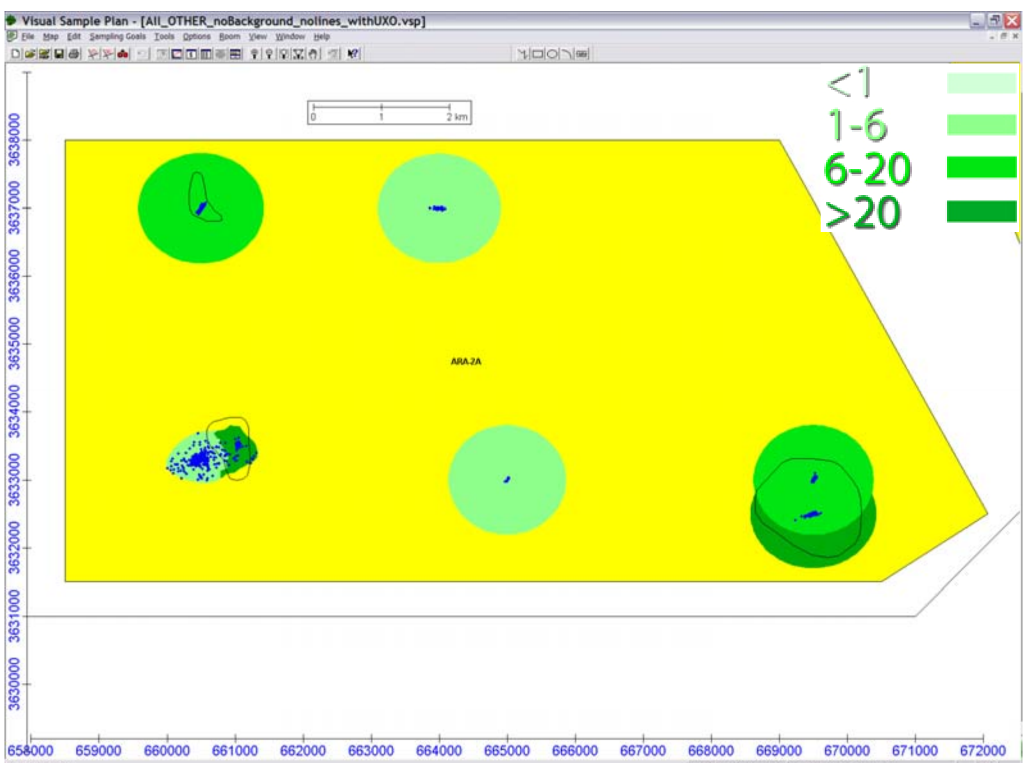


Figure 30: UXO coordinates plotted on ARA-2A simulated target map with perimeter delineation (black lines) based on the 298 m spaced transect design.

Figure 31 shows the indicator kriging probability levels for ARA-2A using an indicator kriging threshold of 46 and 45 anomalies per acre for the 298 m and 344 m spaced-transects respectively. Only areas with a probability of 0.05 or greater of exceeding the threshold value are shown by color-filled contours. These areas were included as part of the information used in determining the final target boundaries. Variogram model parameters used in the kriging estimates are listed in Appendix A

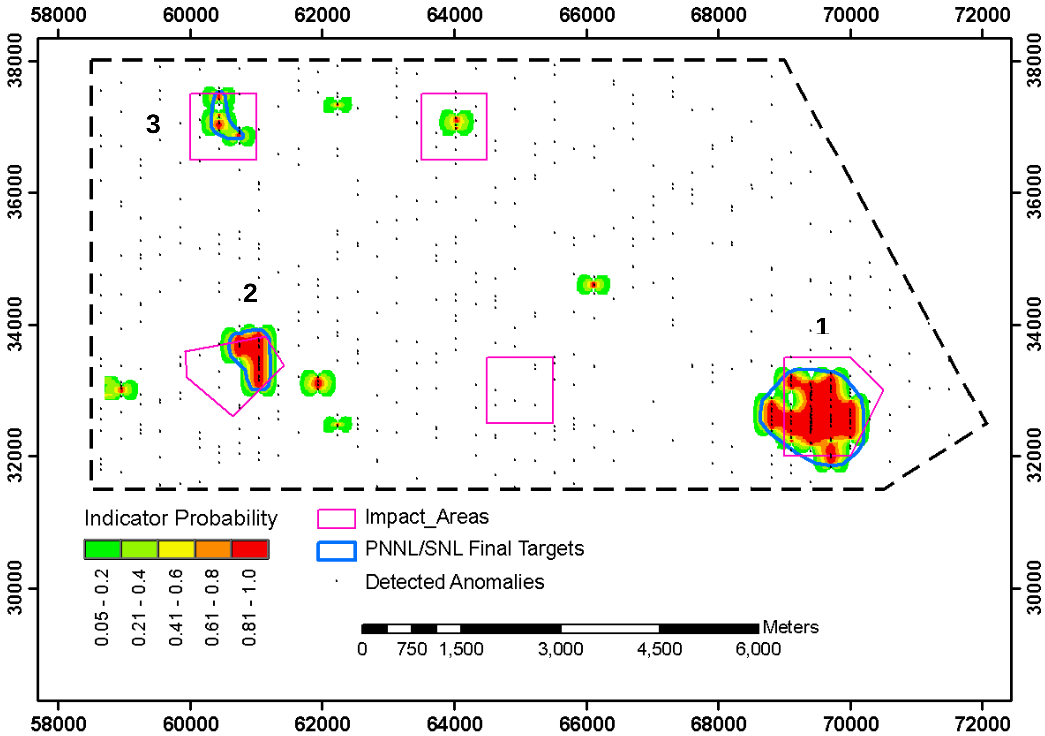
The Indicator Kriging results for the 298 m spaced transects (1 m width) show several small isolated areas outside of the final target delineations. These were considered too small to be actual target sites and so were not incorporated into the final target boundaries. These small areas do not appear in the 344 m spaced transect (2 m width) results. In the 1 m width transect scenario there were two impact areas that were not properly identified. Although one of these appears as a relatively high-probability area in the Indicator Kriging results, its small size precluded it from inclusion without additional information. This same area was identified using the 2 m transects with the addition of supplemental east-west transects. The single impact area not identified in either transect scenario appears to have a relatively small footprint and low anomaly density (see Figure 32).

Figures 32 and 33 show the kriged estimate and actual cell-averaged density for the 298 m and 344 m spaced transect scenarios respectively. In general, the kriged estimates for both scenarios provide a good representation of the basic anomaly distribution considering the limited sampling. As shown by the actual anomaly density figures, the one impact area not identified in either sampling scenario does not contain anomaly concentrations significantly above the surrounding area.

Figures 34 and 35 show comparison box and whisker plots for each of the target areas and for the entire ARA-2A range. The data compared are the grid cell averaged true magnetic anomaly data and the estimated kriging values using data from the 1 m width transects. Similar information for the 2 m width transects are shown in Figures 36 through 38.

These figures show that, in general, the interquartile range and mean of the original anomaly data set is well represented by the kriged estimates, but the range of the estimated values is typically smaller than the true data set ranges. This result is typical for estimates made with a smoothing algorithm such as kriging.

Table 11 presents a comparison of some basic statistics from the original and estimated anomaly data sets. It shows that the mean of the estimated density for each of the delineated target areas are all within approximately 16% of the actual mean, and the mean for the entire site is within 2% of the actual mean. With the exception of Impact Area 2, that has some issues with how the Fort Ritchie data were simulated, the mean density of each target area is within 10 percent of the true mean value.



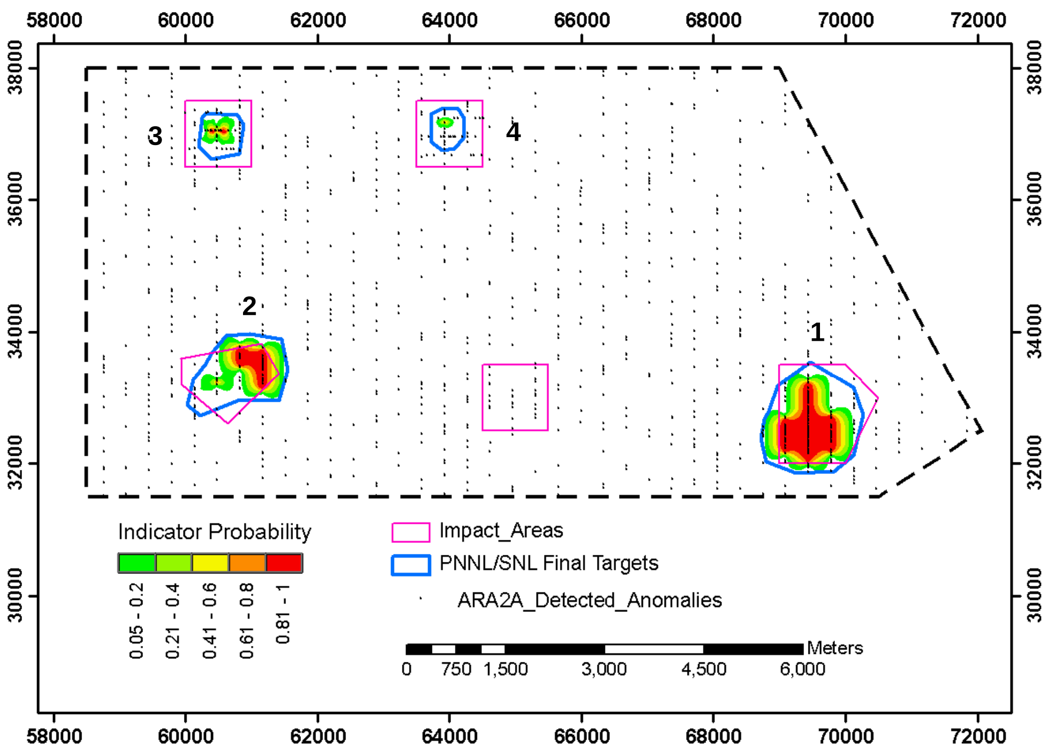


Figure 31: Indicator kriging probability levels for ARA-2A. Top figure shows levels for 1 m wide transects spaced at 298 m; bottom figure shows levels for 2 m wide transects spaced at 344 m. Numbers indicate final target identifiers.

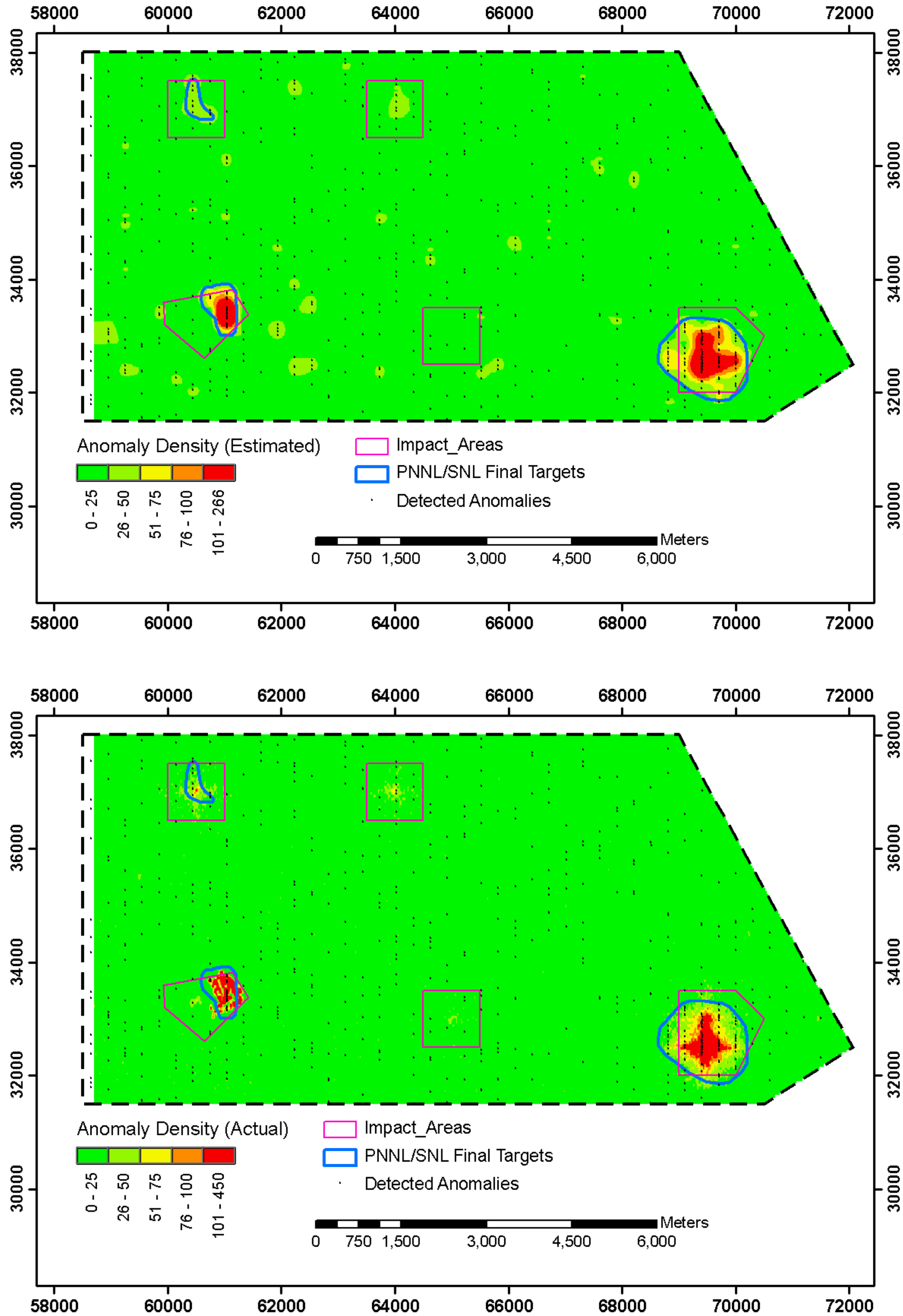


Figure 32: Magnetic anomaly densities in anomalies per acre for ARA-2A. Top figure shows kriged density levels developed using 1 m width transects; bottom figure shows actual cell-averaged density levels.

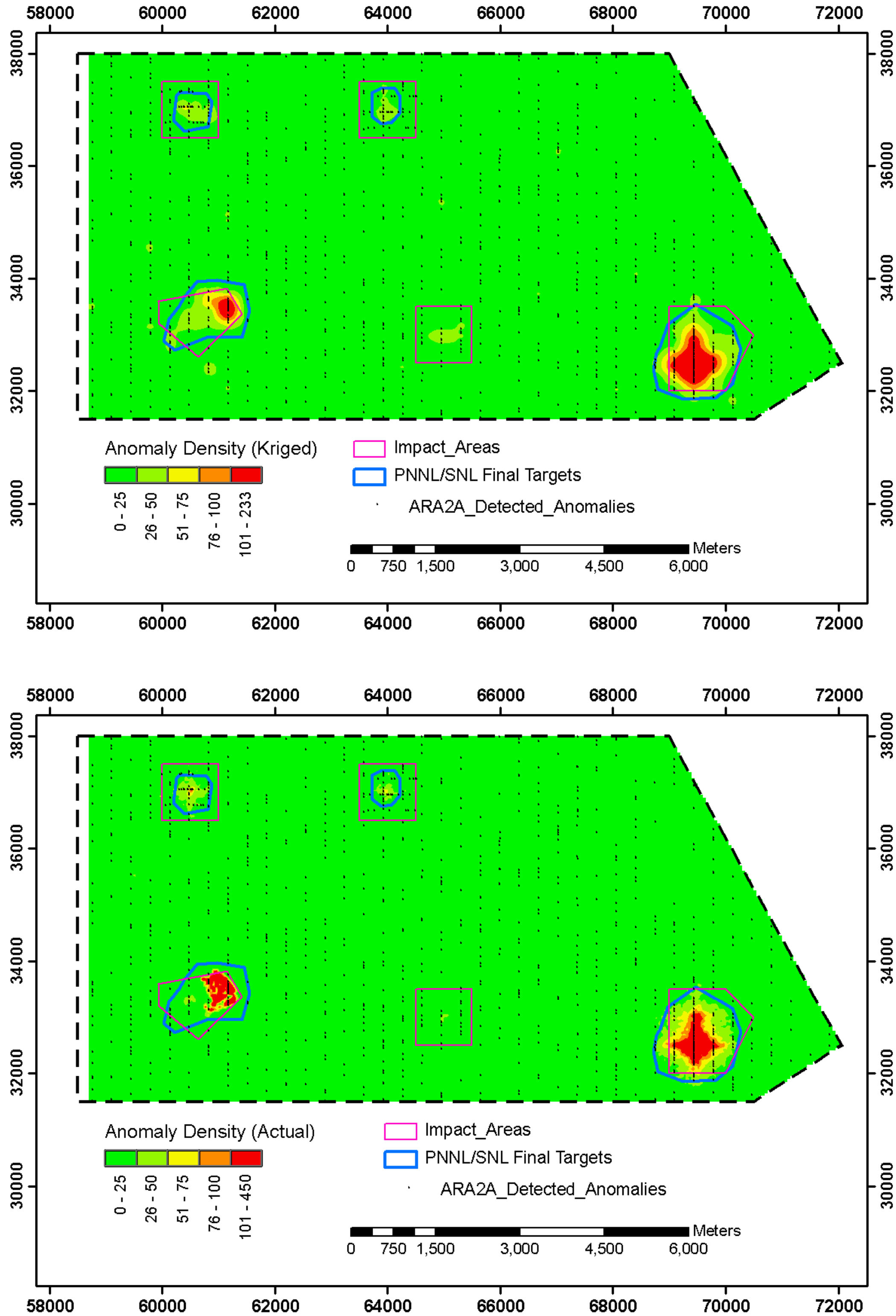
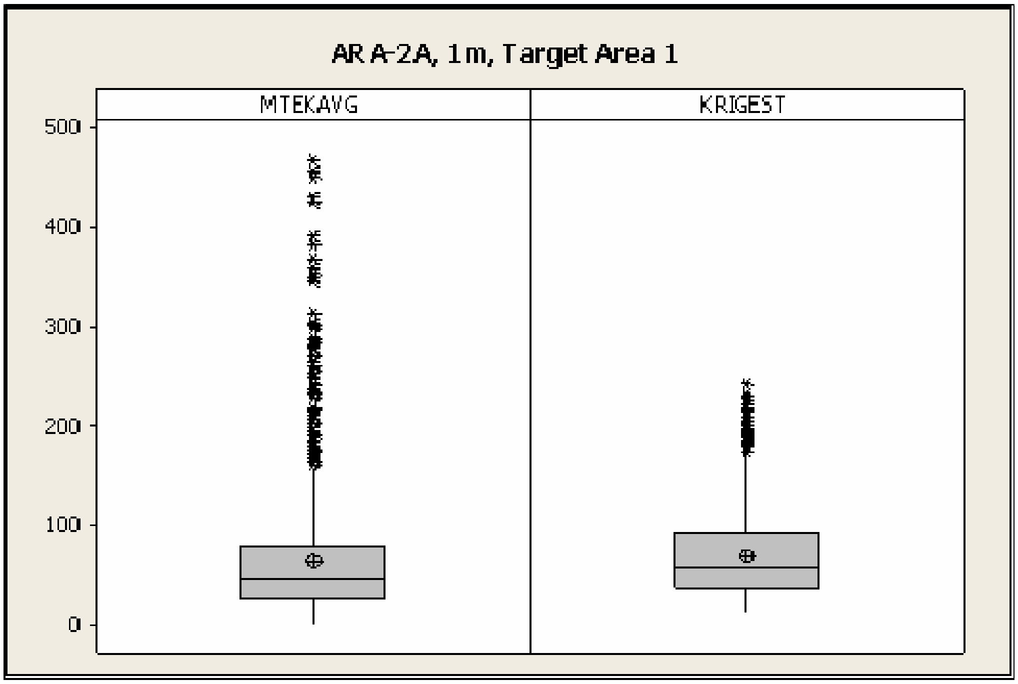


Figure 33: Magnetic anomaly densities in anomalies per acre for ARA-2A. Top figure shows kriged density levels developed using 2 m width transects; bottom figure shows actual cell-averaged density levels.



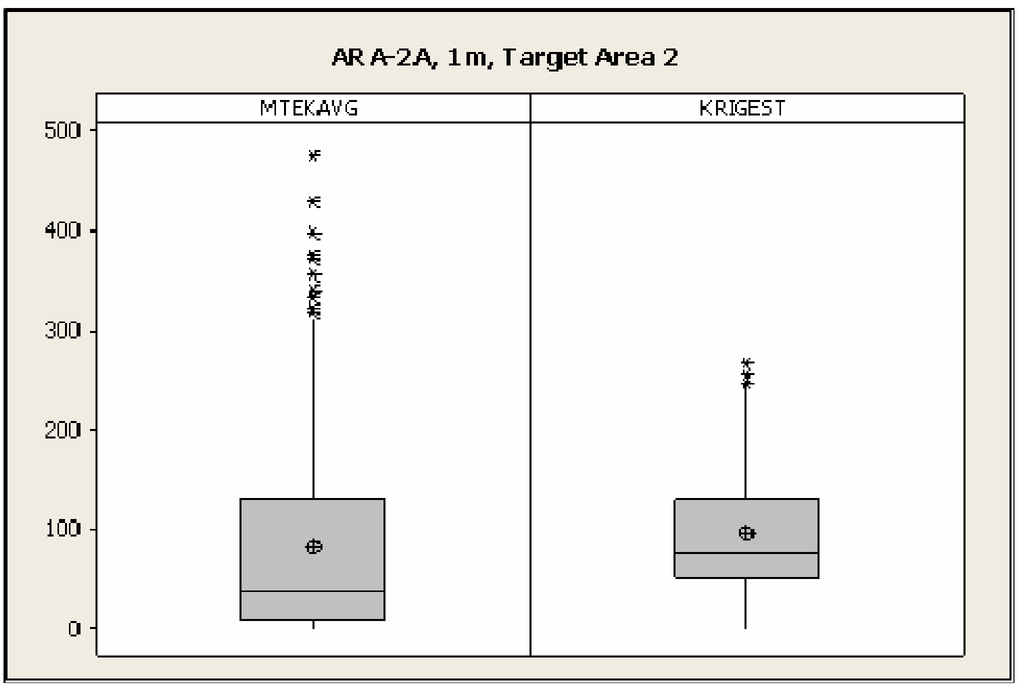
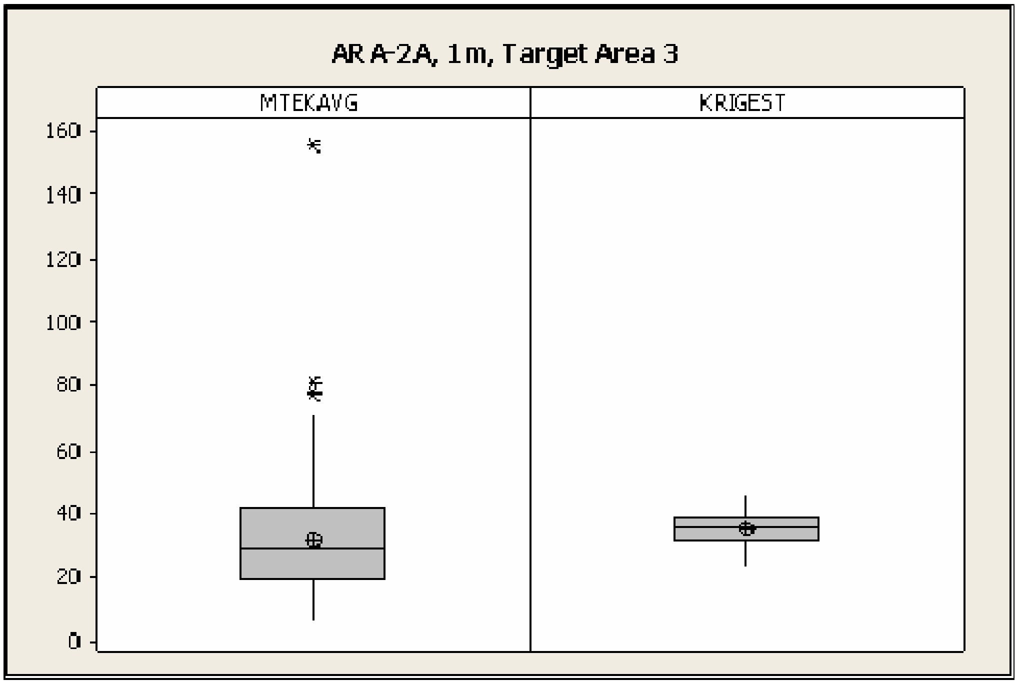


Figure 34: Box and whisker plots for ARA-2A, 1 m wide transect scenario comparing Mitretek range anomaly densities (Mtekavg) and kriging estimated densities (Krigest) for individual target areas. Boxes represent interquartile range with median shown by horizontal line. Vertical lines show largest value within upper limit (Q3+1.5(Q3-Q1) and smallest value within lower limit (Q1-1.5(Q3-Q1) with outliers beyond this range shown by asterisks. Mean is shown by circle with cross.



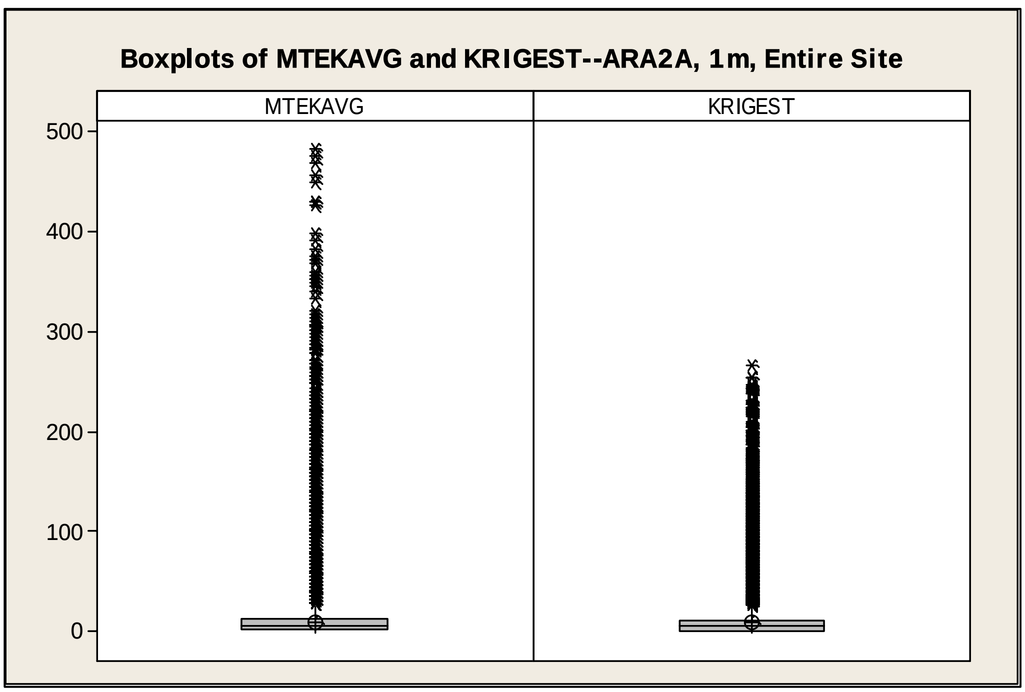
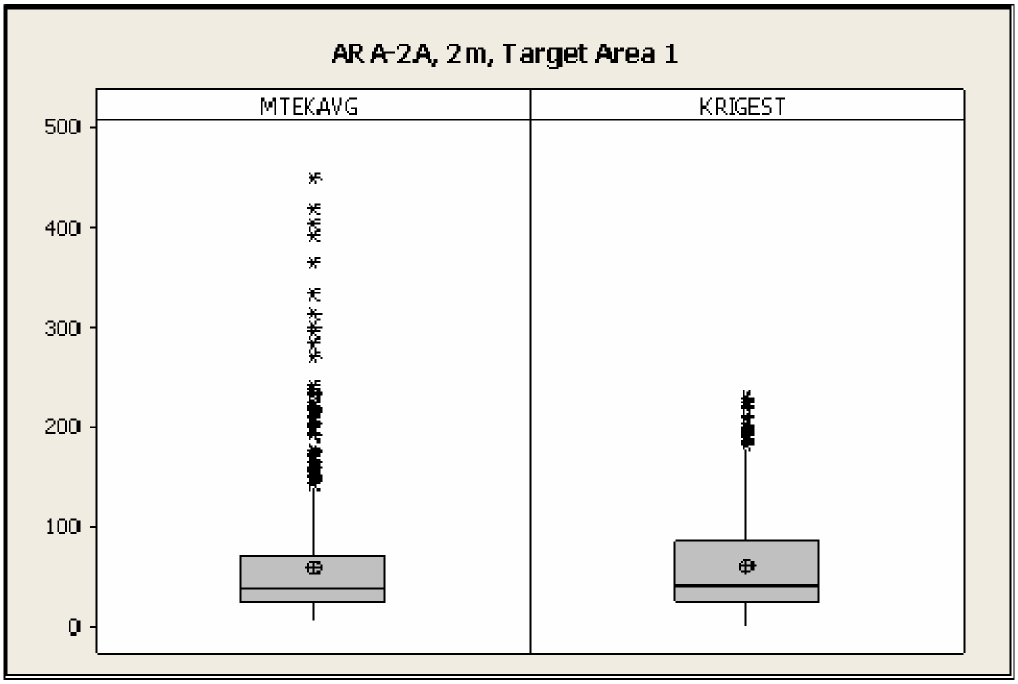


Figure 35: Box and whisker plots for ARA-2A, 1 m wide transect scenario comparing Mitretek range anomaly densities (Mtekavg) and kriging estimated densities (Krigest) for Target Area 3 (top plot) and entire site (bottom plot). Boxes represent interquartile range with median shown by horizontal line. Vertical lines show largest value within upper limit (Q3+1.5(Q3-Q1) and smallest value within lower limit (Q1-1.5(Q3-Q1) outliers beyond this range shown by asterisks. Mean is shown by circle with cross.



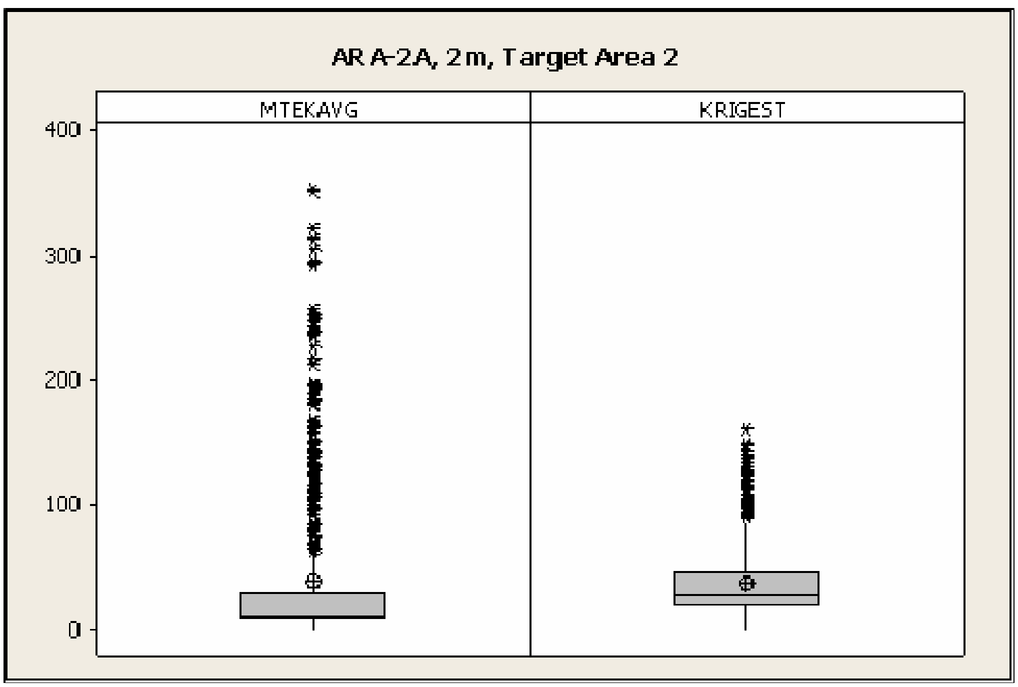


Figure 36: Box and whisker plots for ARA-2A, 2 m wide transect scenario comparing Mitretek range anomaly densities (Mtekavg) and kriging estimated densities (Krigest) for individual target areas. Boxes represent interquartile range with median shown by horizontal line. Vertical lines show largest value within upper limit (Q3+1.5(Q3-Q1) and smallest value within lower limit (Q1-1.5(Q3-Q1) outliers beyond this range shown by asterisks. Mean is shown by circle with cross.

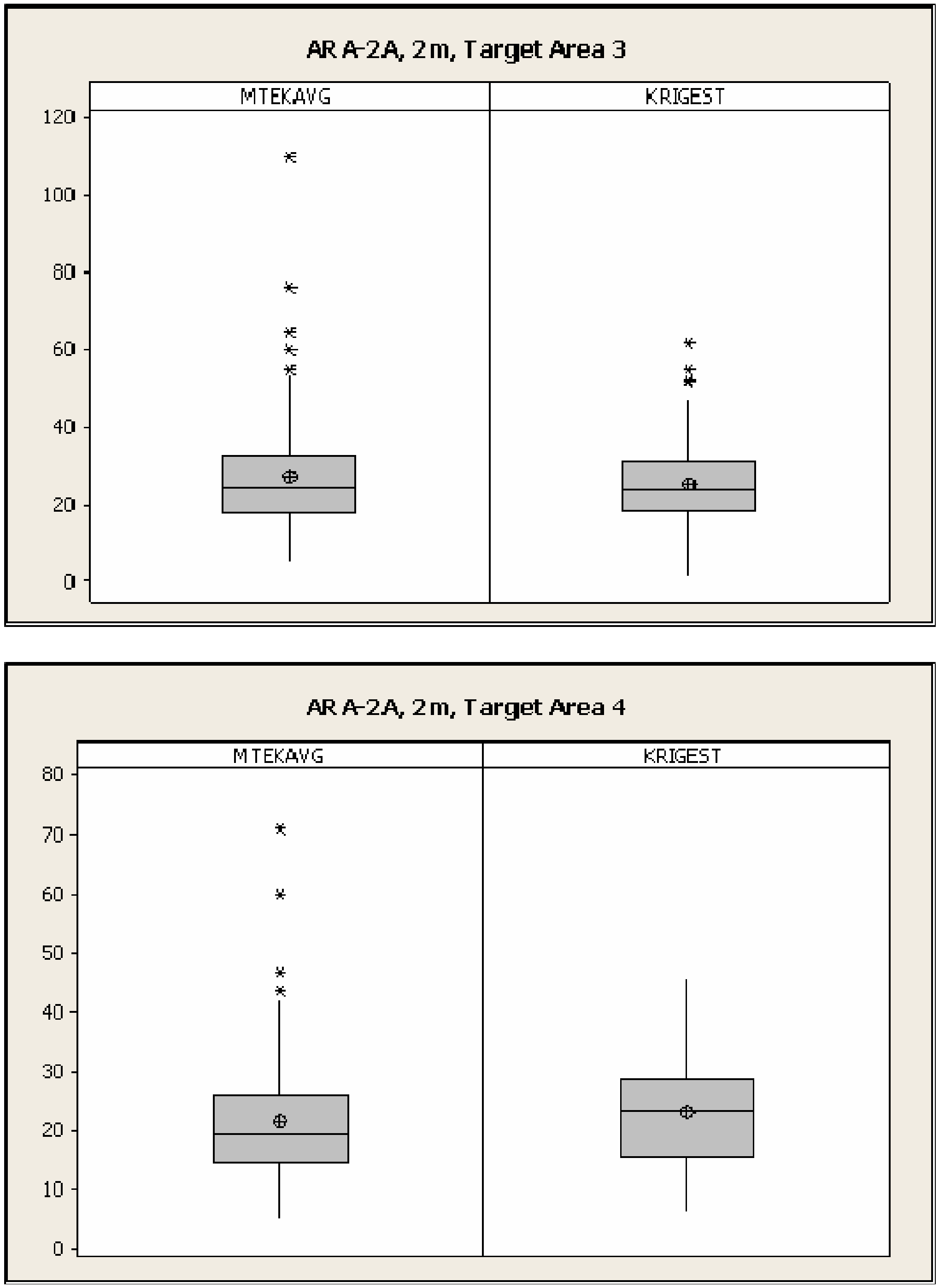


Figure 37: Box and whisker plots for ARA-2A, 2 m wide transect scenario comparing Mitretek range anomaly densities (Mtekavg) and kriging estimated densities (Krigest) for individual target areas. Boxes represent interquartile range with median shown by horizontal line. Vertical lines show largest value within upper limit (Q3+1.5(Q3-Q1) and smallest value within lower limit (Q1-1.5(Q3-Q1) outliers beyond this range shown by asterisks. Mean is shown by circle with cross.

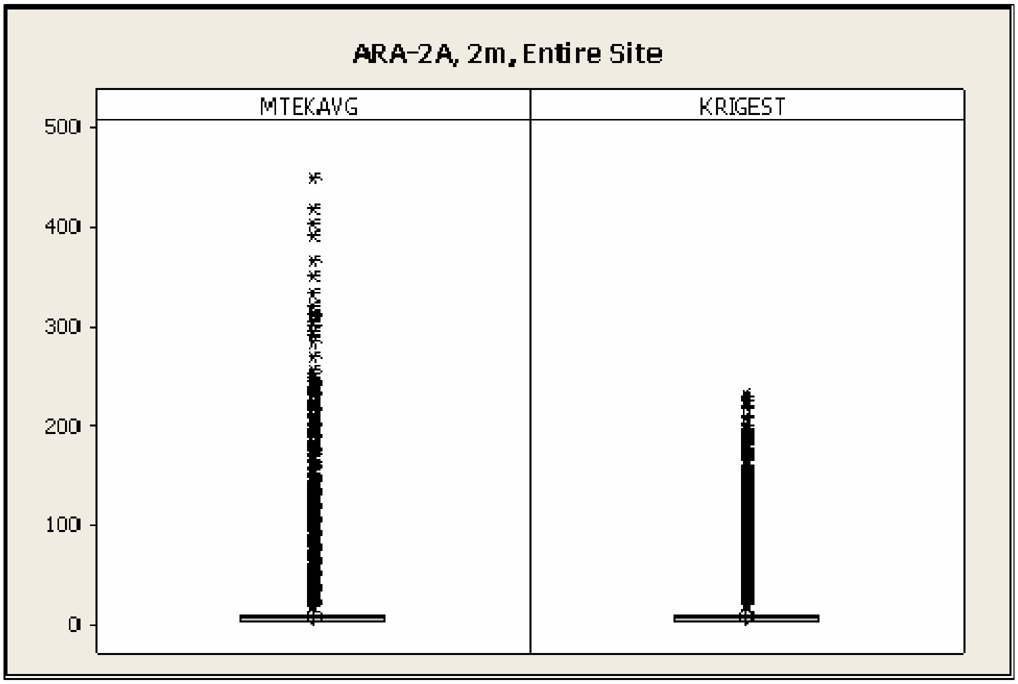


Figure 38: Box and whisker plots for ARA-2A, 2 m wide transect scenario comparing Mitretek range anomaly densities (Mtekavg) and kriging estimated densities (Krigest) for individual target areas.

	Area	Source	Mean	Mean Diff.	Std Dev	Min	Max
1 m Width Transect	Target 1	Mtk	64.5	9.5%	60.6	0	469.4
		KrigEst	70.6		41.8	11.56	242.8
	Target 2	Mtk	83.0	15.8%	95.3	0	475.9
		KrigEst	96.1		59.0	0	265.9
	Target 3	Mtk	32.2	10.2%	19.0	6.5	155.4
		KrigEst	35.5		5.6	23.1	46.2
	Entire Range	Mtk	9.8	0%	16.7	0	482.4
		KrigEst	9.8		15.5	0	265.9

	Area	Source	Mean	Mean Diff.	Std Dev	Min	Max
2 m Width Transect	Target 1	Mtk	60.4	2.5%	58.0	6.5	450.0
		KrigEst	61.9		48.6	1.3	232.5
	Target 2	Mtk	39.1	-1.8%	63.4	0	352.9
		KrigEst	38.4		30.1	0	161.1
	Target 3	Mtk	27.1	-7.7%	13.8	4.9	110.1
		KrigEst	25.0		11.0	1.1	61.8
	Target 4	Mtk	21.5	8.4%	10.3	4.5	71.2
		KrigEst	23.3		8.7	6.3	42.7
	Entire Range	Mtk	9.8	2%	15.8	0	450.0
		KrigEst	10.0		13.7	0	232.5

Table 11: Comparison of Kriged estimated (KrigEst) and actual (Mtk) magnetic anomaly densities for ARA-2A range. Estimated anomaly densities were developed using 1 m wide transects (upper table) and 2 m wide transects (lower table).

Located in the south-central area of ARA-2A is an impact area which was not identified in either sampling scenario. This target area provides an example of how a target with little ordnance related anomalies in a region with a relatively high clutter density can go undetected. Although several transects crossed this area, only a few anomalies were detected (see Figure 31). Figure 39 presents three plots showing the actual anomaly distribution for this impact area. The top plot in Figure 39 shows anomalies due to range activities (UXO and fragments), the middle plot shows the clutter anomalies, and the bottom plot shows the combination of all anomalies. A rectangle containing all range-related anomalies for this impact area (black box in Figure 39) occupies an area of 610 acres. Within this box there are 1,216 range-related anomalies (UXO and fragments) and 5,251 clutter anomalies. These give a clutter density of 8.6 anomalies per acre and a UXO/fragment density of 2.0 anomalies per acre. The ratio of range-related anomaly density to clutter density is then 0.23.

For a similar sized area (~610 acres) centered over Target 4 which was identified in the 2 m width transect sampling, the densities are 4.7 anomalies per acre for the range-related anomalies and 6.3 anomalies per acre for the clutter. This gives a range-to-clutter ratio of 0.75 which is three times that of the unrecognized impact area. The unrecognized impact area contains only a small amount of range-related anomalies, and is located in an area with a larger amount of clutter. This combination makes detection of this feature difficult. In addition, the spatial distribution of range-related fragments within this impact area displays a pattern which is unexpected for explosive related dispersion. Close examination of the top plot in Figure 39 reveals that the range-related anomalies are concentrated in a cross-pattern centered at the target location. Although range-related anomalies are distributed through-out the area, there are notable linear concentrations of anomalies oriented east-west and north-south. These concentrations are not explained by the firing path alignment and are observed at most of the other target locations.

The concentration of range-related anomalies into a cross-like pattern makes detection of the targets more difficult in that it reduces the probability of encountering a high-density area using linear transects (depending on orientation) and can result in unexpected patterns in the detected anomalies. Alternate transect design criteria may have been employed to detect this type of unexpected pattern.

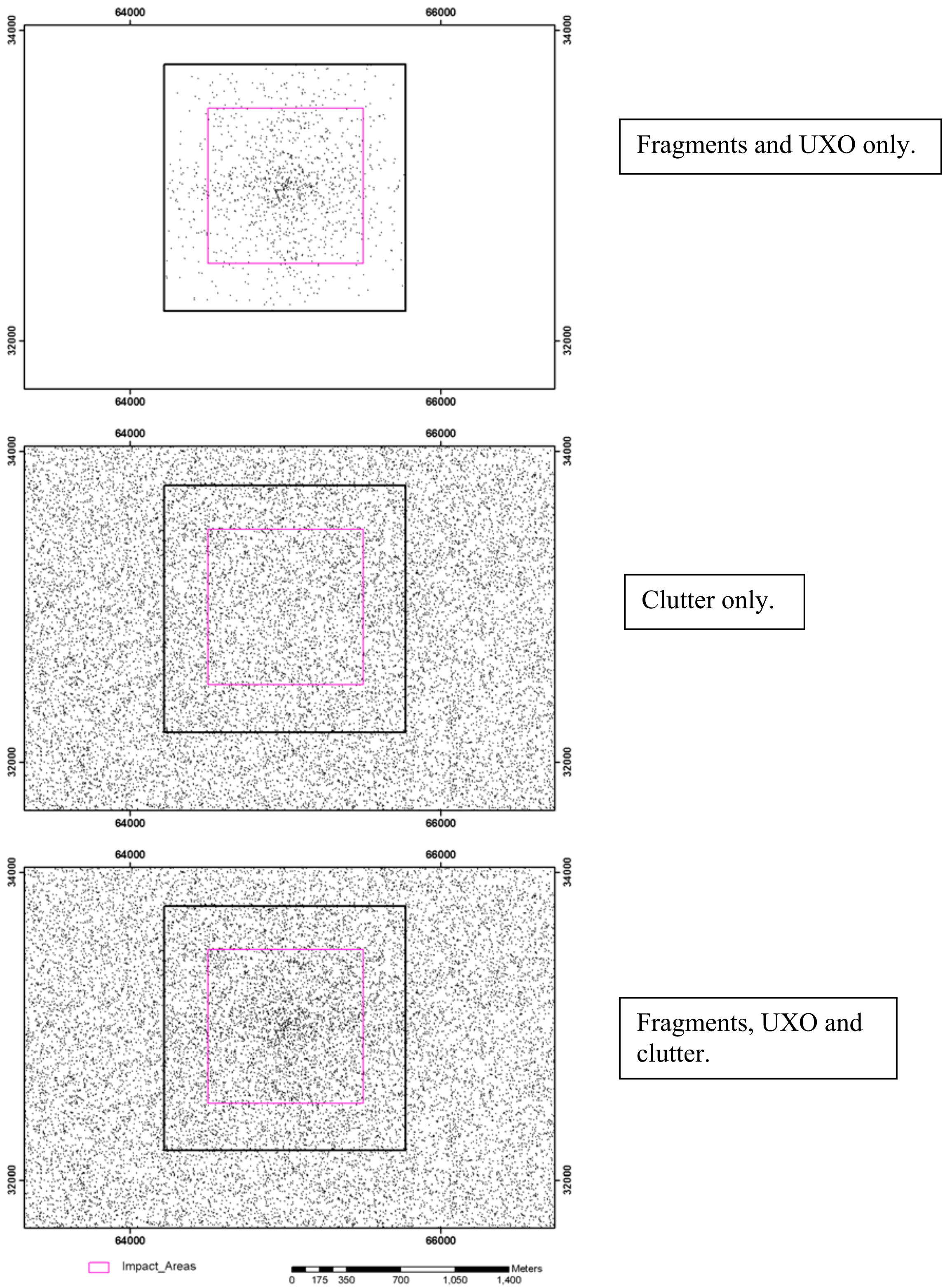


Figure 39: Distribution of anomalies for ARA-2A impact area not identified using transect data. Black-outlined box encompasses all range related anomalies.

4.3.2.3 ARA-2A Power Curve Analysis of Discrepancies Between Designs

Figure 41 shows two VSP calculated power curves for the 298 m (1 m wide) and 344 m (2 m wide) spaced transect designs based on the average known maximum possible target area size for the simulated target areas, the known background density for the site, and other inputs shown in Figure 40. The maximum size of the simulated target areas for ARA-2A had a slight oval shape with a semi-major radius ranging from 865 to 925 m and a semi-minor radius ranging from 801 to 809 m. The two power curves in Figure 41 are based on the average semi-minor and semi-major radii for this area. Because there is very little difference between the power curves in Figure 41 and the actual power curves for each different target area, one set of power curves, which demonstrates the difference between the two designs in ARA-2A, is shown. On Figure 41, these two power curves have reference points showing the densities of the two least dense target areas that were missed. It is no surprise that the low density target areas were not always detected given the probabilities of detection shown in Figure 41. Luckily, the 344 m spaced transect design corresponding to the bottom power curve did identify the target area with a density of 15.47 anomalies per acre (5.35 anomalies per acre above background). These two power curves are also a function of transect width and the 2 m wide transect design with a wider spacing between transects had a higher probability of detecting the actual target sizes that were simulated.

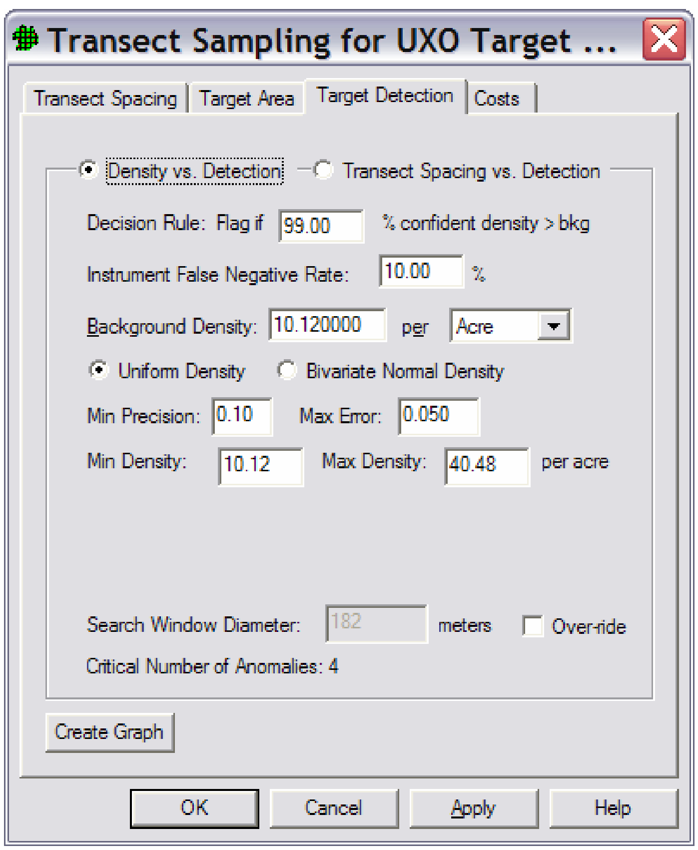


Figure 40: Other inputs used to calculate power curves in Figure 41. Min Precision and Max Error allow the user to control the accuracy of the simulation. Min and Max Density per acre sets the range of the x axis of the power curve

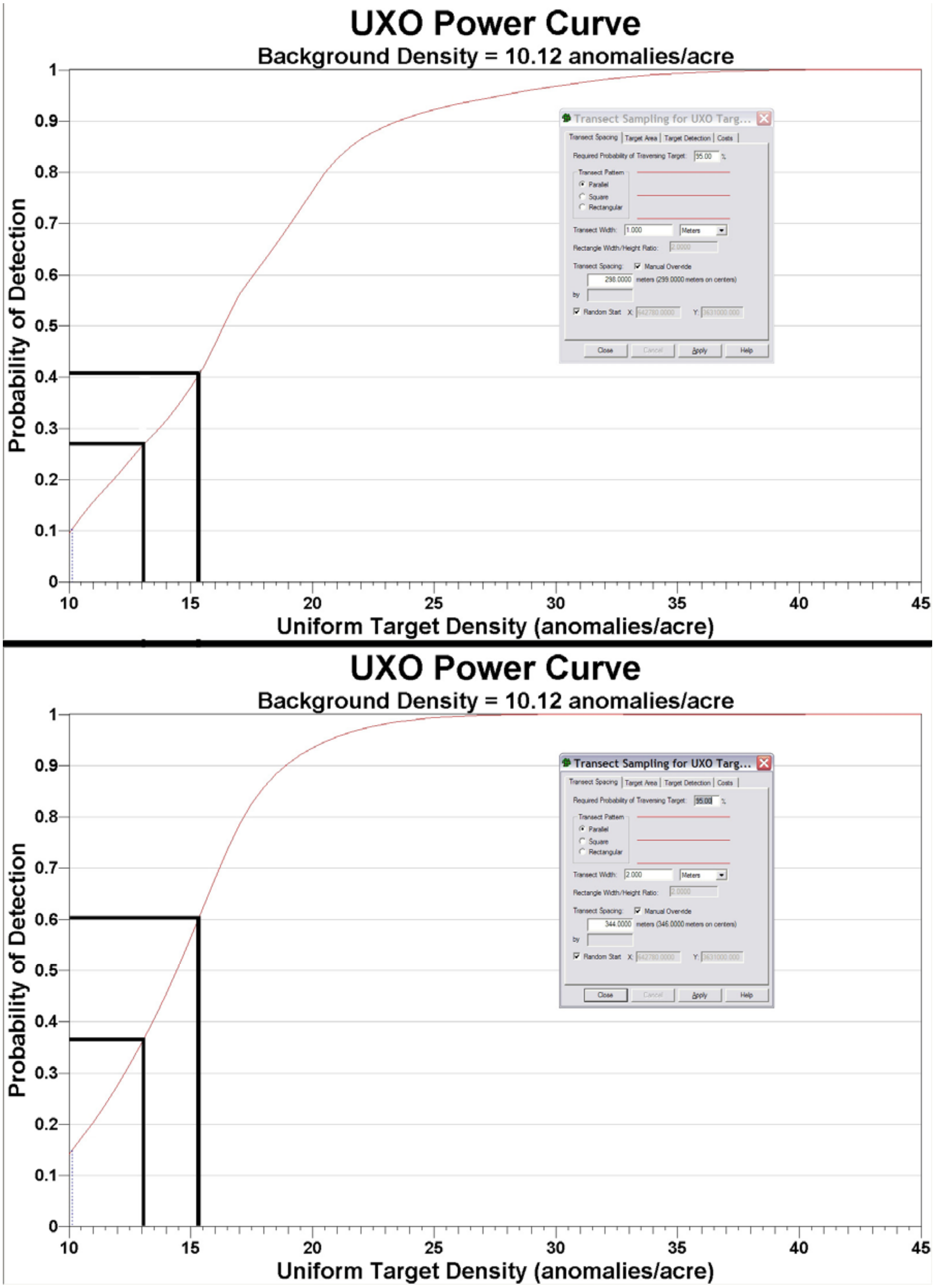


Figure 41: Two VSP calculated power curves for the 298 m 1 m wide (top) and 344 m 2 m wide (bottom) spaced transect designs

4.3.3 Artillery Range Area 2B (ARA-2B)

Artillery Range Area 2B covered a large area (37,450 acres). It was also used for 155mm projectile and 4.2" mortar exercises and was estimated to have a 427 by 280 m elliptical target area of interest. Two scenarios were created for this impact area based on estimating the probability of detecting the defined target area with a desired transect density. Because the actual simulated target areas were much larger than assumed for the transect design the probability of detecting the simulated target area was much higher than 80% power (almost 100% power) for target areas with 30 and 50 anomalies per acre. Thus an explanation of the reasoning for the transect design based on the assumptions is given and then the actual target area sizes are used to show how the transect design performed as a function of the design power. Mitretek simulated two different background densities in this site – 4.05 and 6.07 anomalies per acre (the actual background clutter density was approximately 2 anomalies per acre instead of 4.05 for the western part of the site). See Appendix B for a discussion about the actual background densities received from Mitretek. The ARA-2B background levels may have created some difficulties for identifying low density targets (targets with a density between 0-4 anomalies per acre above background) in areas where the background density was lower than stated. However, the our performance on this impact area, with a fluctuating background, did not differ much from our performance on the other impact areas in the simulation.

4.3.3.1 ARA-2B Transect Designs

Two transect designs based on the ARA-2B impact area were created. Each design was developed to have a desired probability of detecting a certain target area size and density. As with the two previous impact areas, the use of 4.2" mortars and 155mm projectiles created the same assumed 427 m long by 280 m wide elliptical target area.

For scenario 1 greater than 80% probability of identifying the assumed target area size that had a density of 50 anomalies per acre or more when the background was 6 anomalies per acre was desired. Figure 42 shows the power curve for the 344 m spaced transect design shown in Figure 43 which covered 0.58% of the impact area. The second scenario, shown in Figure 44, had a 2 m wide 282 m spaced transect design and covered 0.71% of the impact area. This design was based on the assumptions used to create the power curve in Figure 45. These assumptions were 6 anomalies per acre background level and greater than an 80% probability of detecting the assumed target area with a density of 38 anomalies per acre or more.

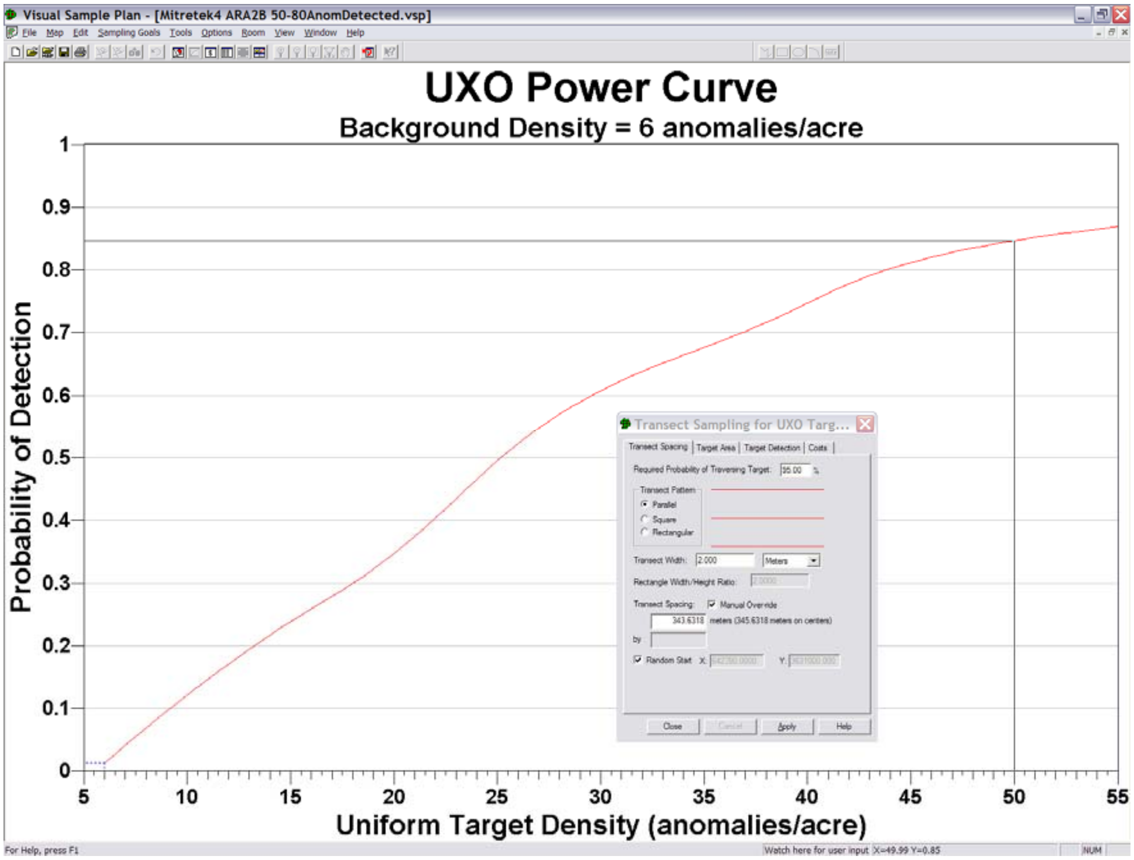


Figure 42: Probability of detecting the assumed target area with a 344 m spaced transect design.

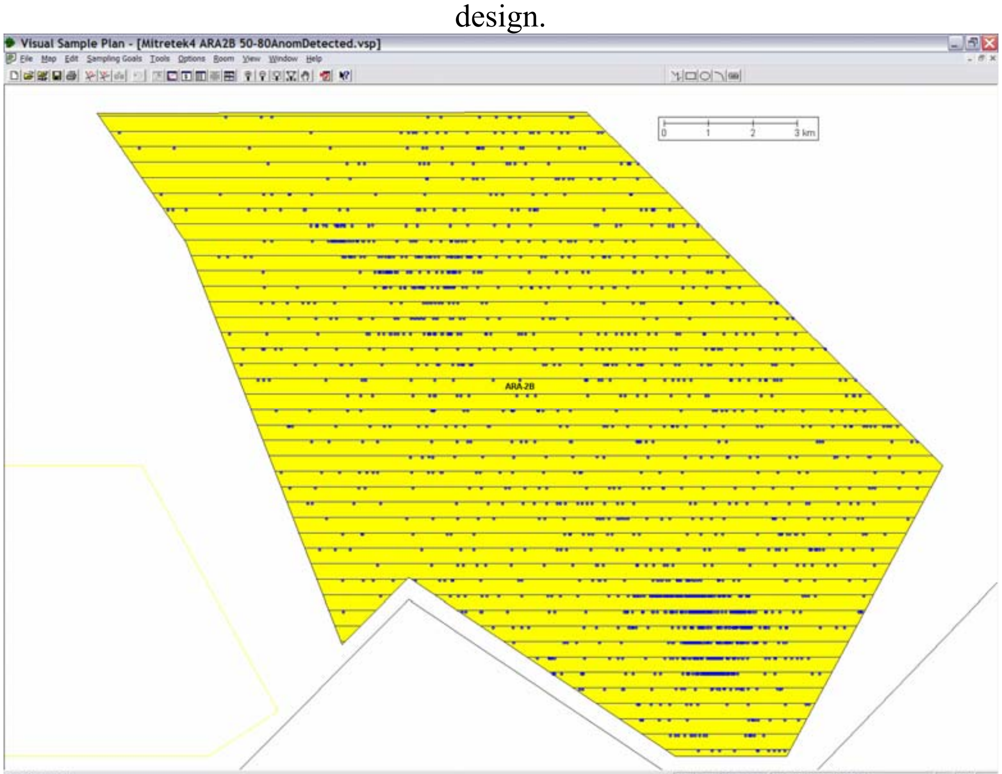


Figure 43: The ARA-2B 344 m spaced transect design with anomalies

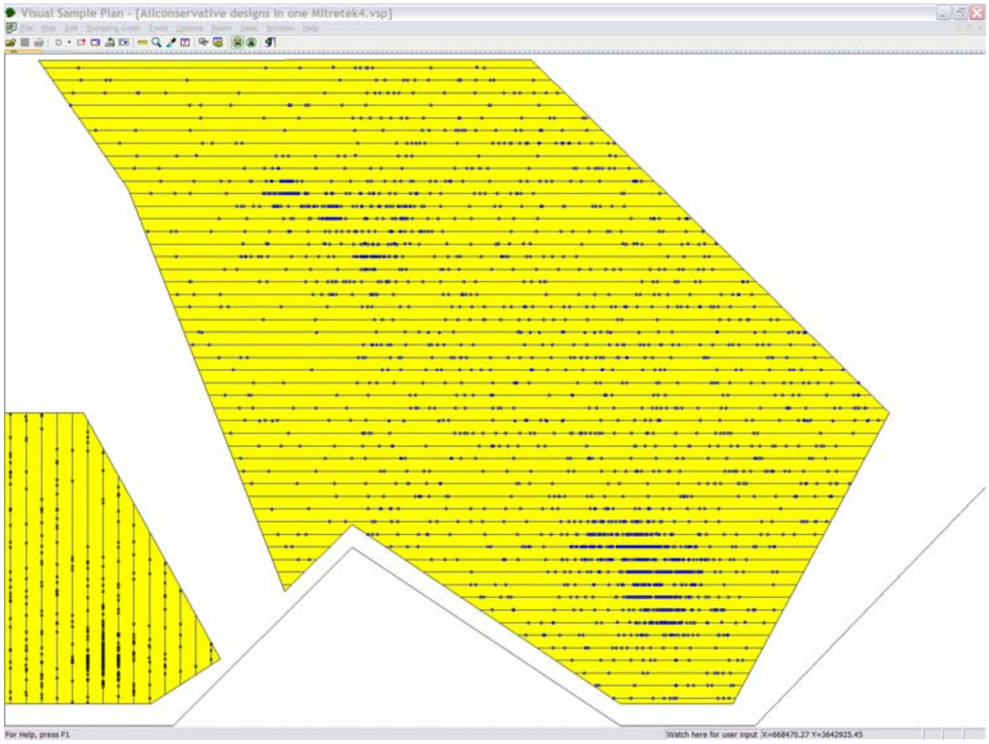


Figure 44: The ARA-2B 282 m spaced transect design with anomalies

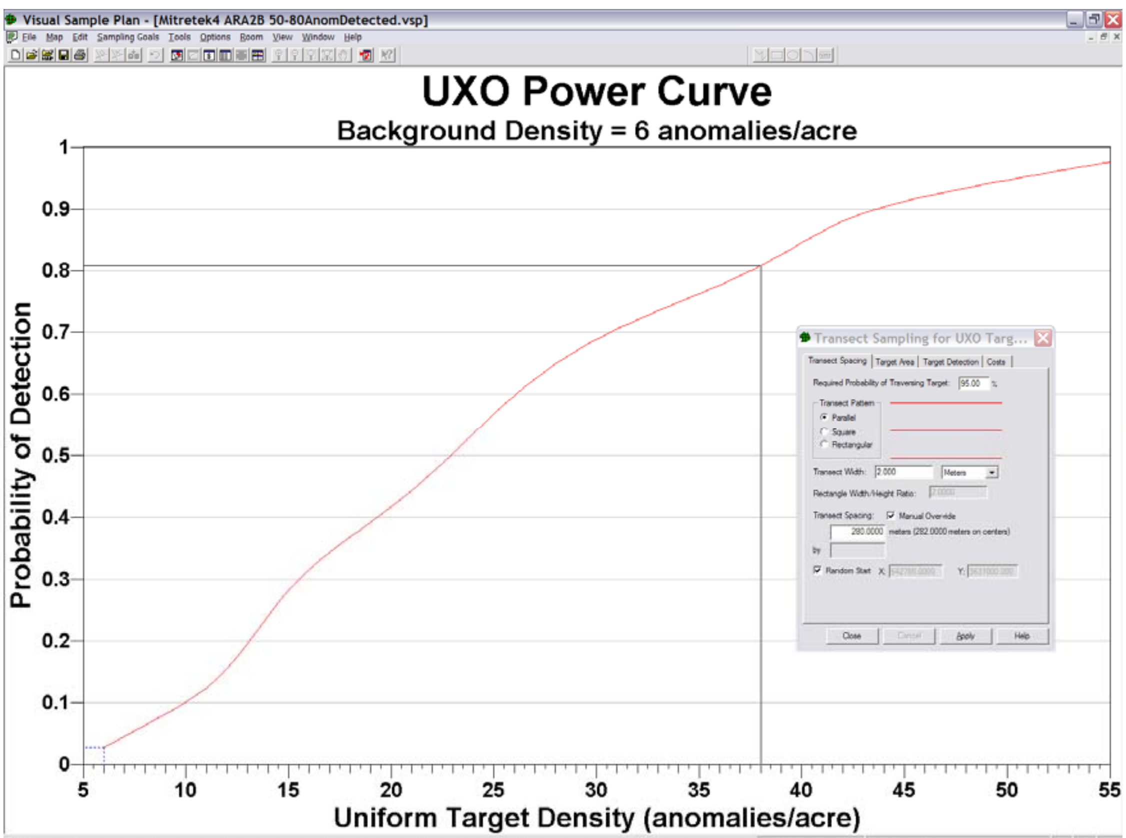


Figure 45: Probability of detecting the assumed target area based on the 282 m spaced transect design.

4.3.3.2 ARA-2B Target Area Identification Results

The assumed target area was much smaller than the actual target areas simulated in this impact area. These assumed larger areas changed the achievable probabilities of detection in the two transect designs. For both designs the probability of detecting the simulated target areas with densities of 50 and 30 anomalies per acre were over 99.9%. Figures 46 and 47 show the power curves based on the site background of 6 anomalies per acre and the average actual target area sizes simulated for each transect design. The average simulated target area was a 1856 by 1628 m ellipse as shown in Figure 48.

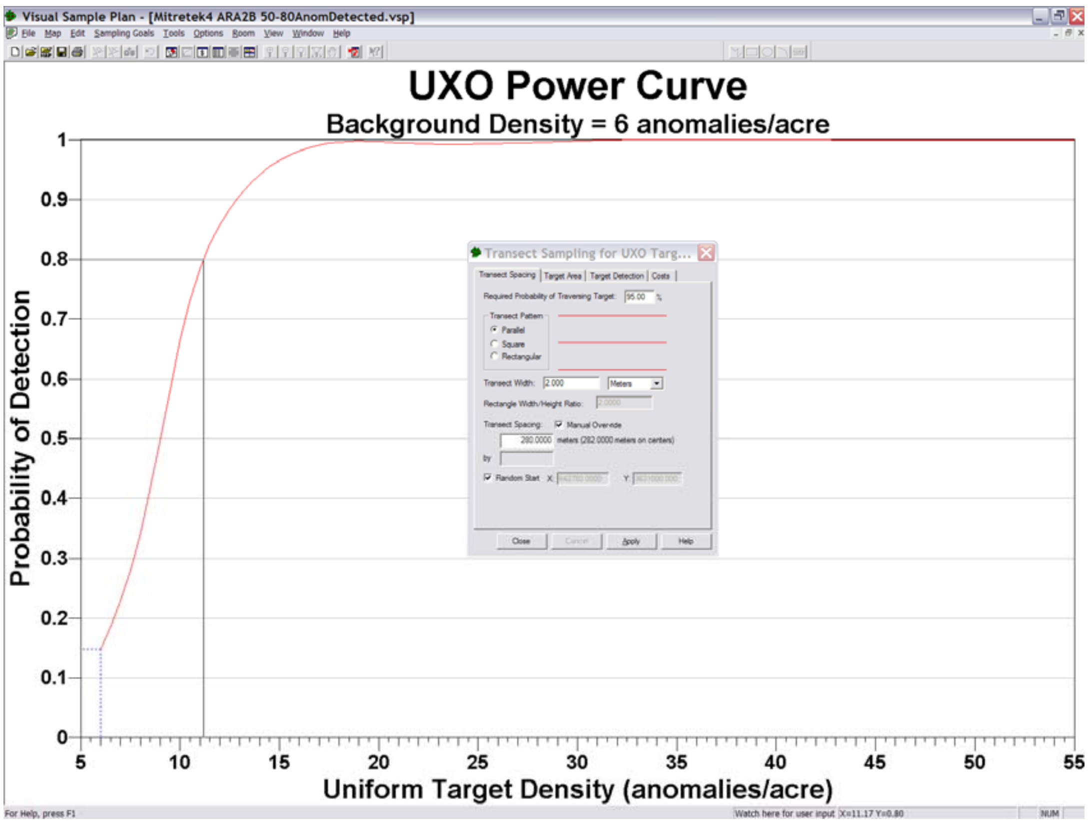


Figure 46: Probability of detecting the simulated target area based on the 282 m spaced transect design.

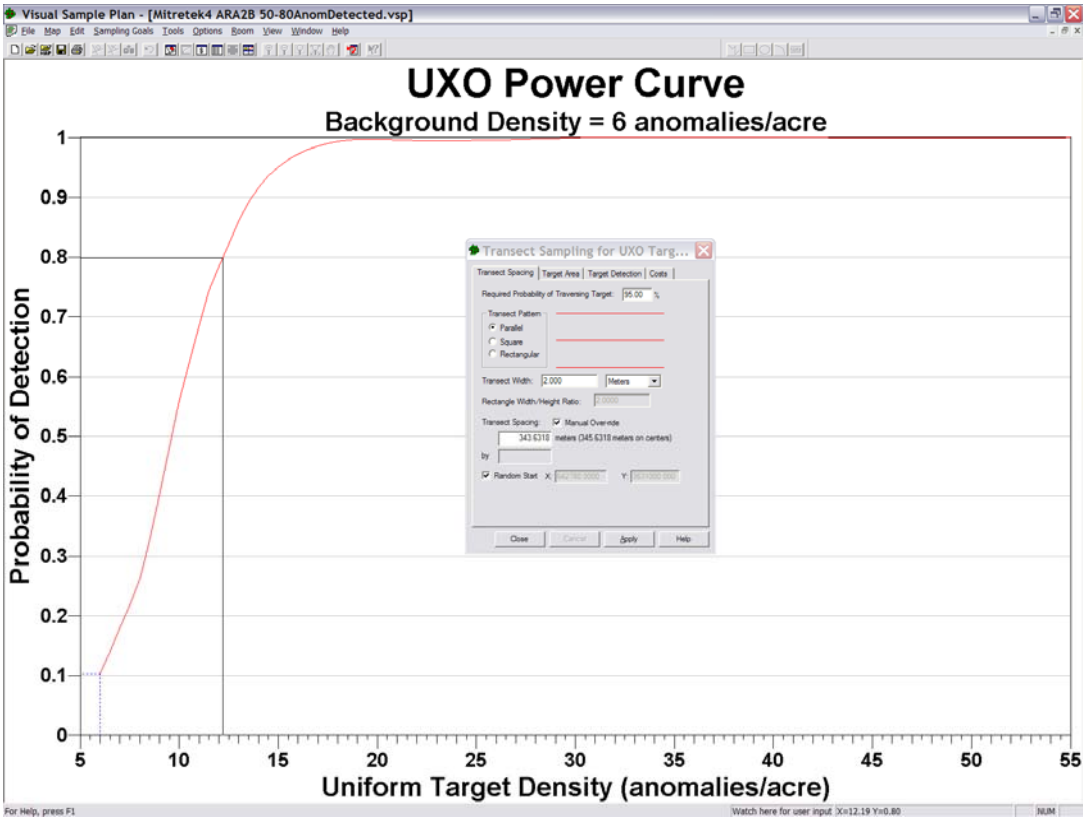


Figure 47: Probability of detecting the simulated target area based on the 344 m spaced transect design.

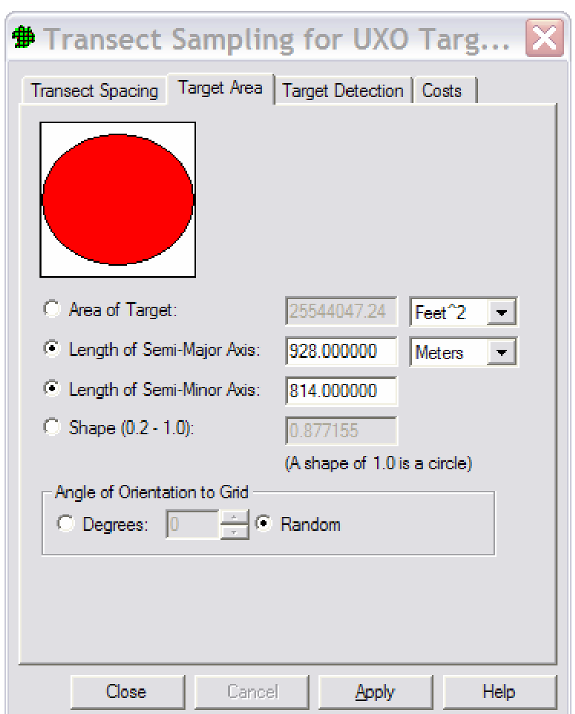


Figure 48: Target area assumptions tab with the average target area value for the ARA-2B simulated targets

Figures 49 and 51 show the target area perimeter estimates for the 344 m spaced transect design. Figure 49 has the flagged areas of concern with the joint PNNL/Sandia target area perimeter estimates (black boundary line around flagged areas) and the simulated target areas color coded by density above background. Figure 51 removes the flagging and plots the actual UXO coordinates (blue points). Similarly, Figures 50 and 52 show the perimeter estimates for the 282 m spaced transect designs. In each design the same target areas and approximately the same defined boundary shapes were identified. Table 12 shows the target area identification results for ARA-2B. For both designs PNNL used a 900 m circular window and a critical density of 18 anomalies per acre.

Density of Target Areas above background	Transect Spacing	Percent of Site Covered with Transects	Total Number of Target Areas	Total Number of UXO	Number of Target Areas Identified	Number of UXO Contained	Percent of Target Areas Identified	Percent of UXO Contained
>6	345m	0.0058	9	253	9	253	1	1
>6	282m	0.0071	9	253	9	253	1	1
<6	345m	0.0058	8	19	1	0	0.125	0
<6	282m	0.0071	8	19	1	0	0.125	0

Table 12: Summary of target area identification results for ARA-2B.

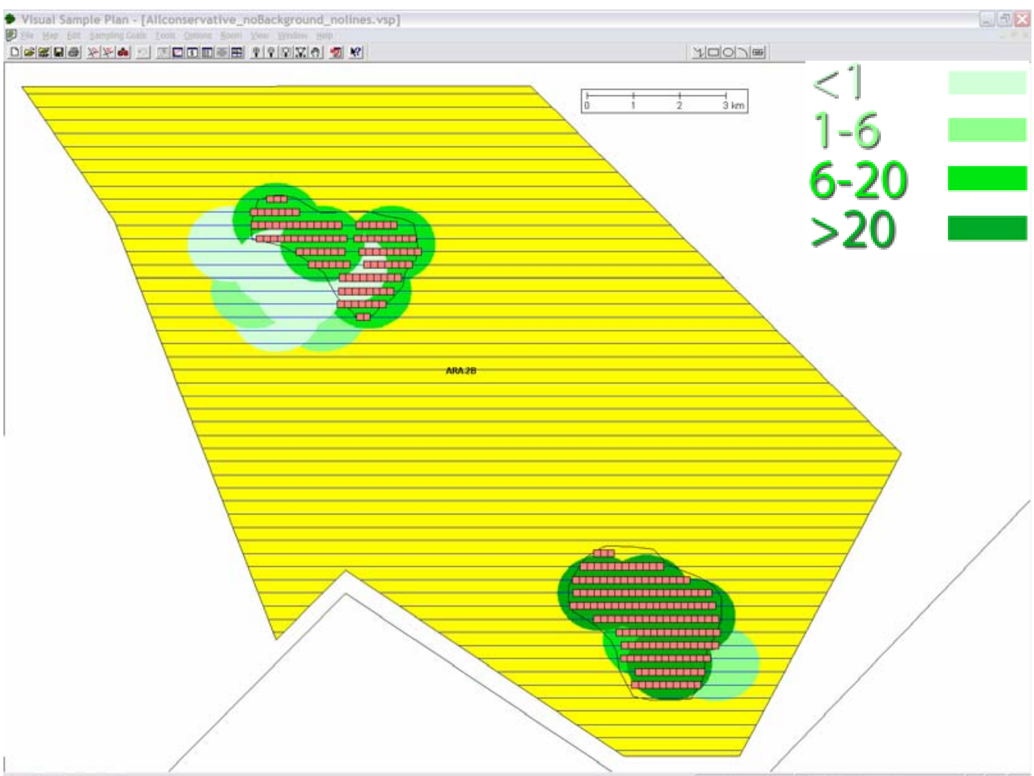


Figure 49: Target area identification based on 282 m spaced transects design with actual target areas identified and color coded by density above background

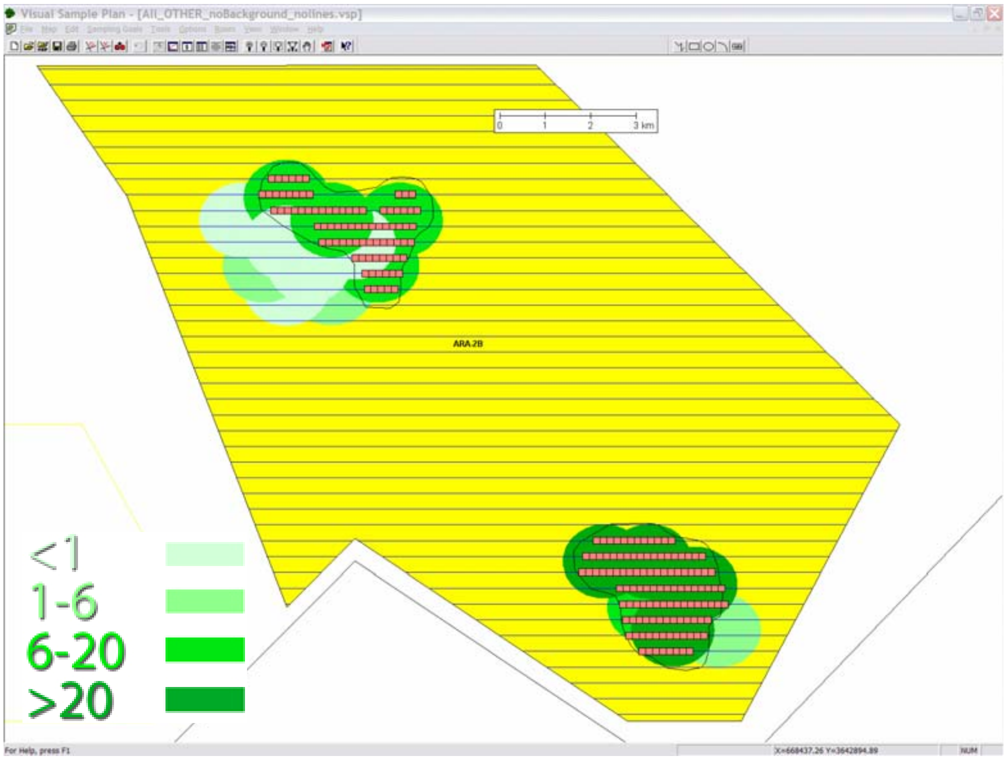


Figure 50: Target area identification based on 344 m spaced transects design with actual target areas identified and color coded by density above background

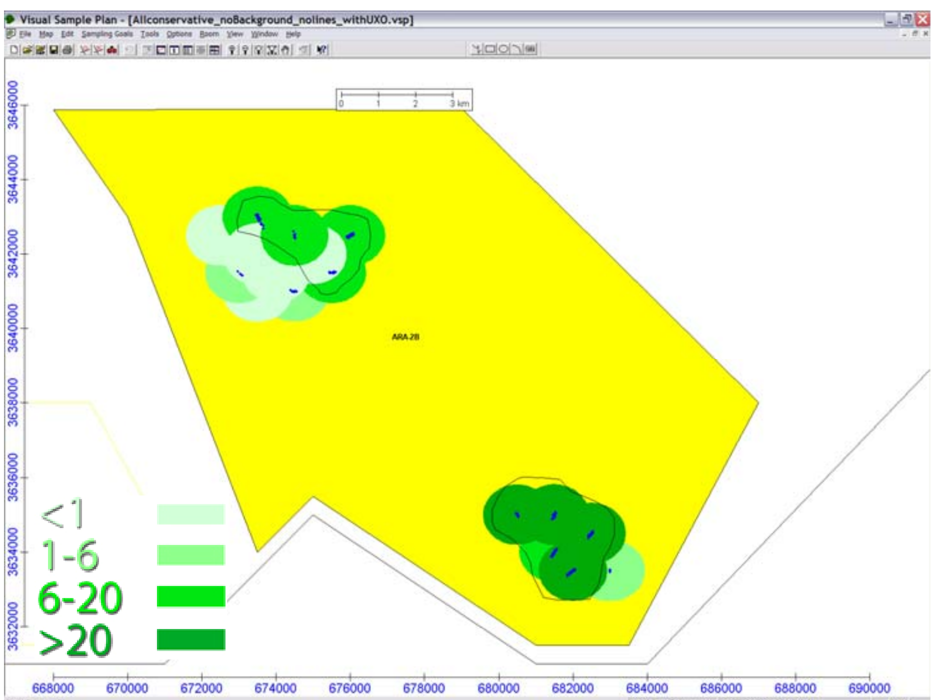


Figure 51: UXO locations (blue clusters) for the 282 m spaced transect design boundaries

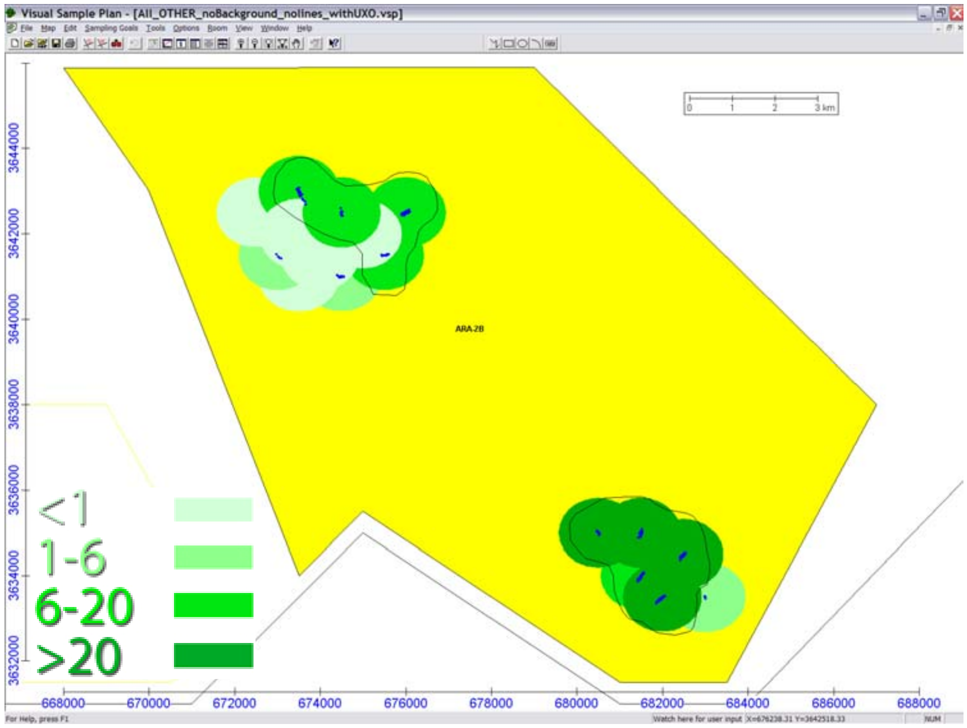


Figure 52: UXO locations (blue clusters) for the 344 m spaced transect design boundaries

For the Indicator Kriging analysis of ARA-2B, SNL used a critical density of 30 anomalies per acre for both transect designs. As before, Sandia identified the targets using a rectangular averaging window 350 m in length with a width equal to the transect sample width, in this case 2 meters.

Figure 53 shows the Indicator Kriging probability levels for ARA-2B using an Indicator Kriging threshold of 30 anomalies per acre for the 282 m and 345 m spaced-transects. Only areas with a probability of 0.05 or greater of exceeding the threshold are shown by color-filled contours. These areas were included as part of the information used in determining the final target boundaries. Variogram model parameters used in the kriging estimates are listed in Appendix A.

The Indicator Kriging results for both transect designs show several small isolated areas outside of the final target delineations. These were considered too small to be actual target sites and so were not incorporated into the final target boundaries. In general, the target areas delineated by the Indicator Kriging are similar between the two sampling scenarios. For Target Area 2 there is a notable difference along the north-eastern boundary. For the 345 m spaced transects, this margin extends further to the north-east outside of the simulated impact area. The boundary for the 282 m spaced transects more closely follows the impact area boundary indicating that the finer transect spacing is acting to constrain the boundary because of the additional sampling locations.

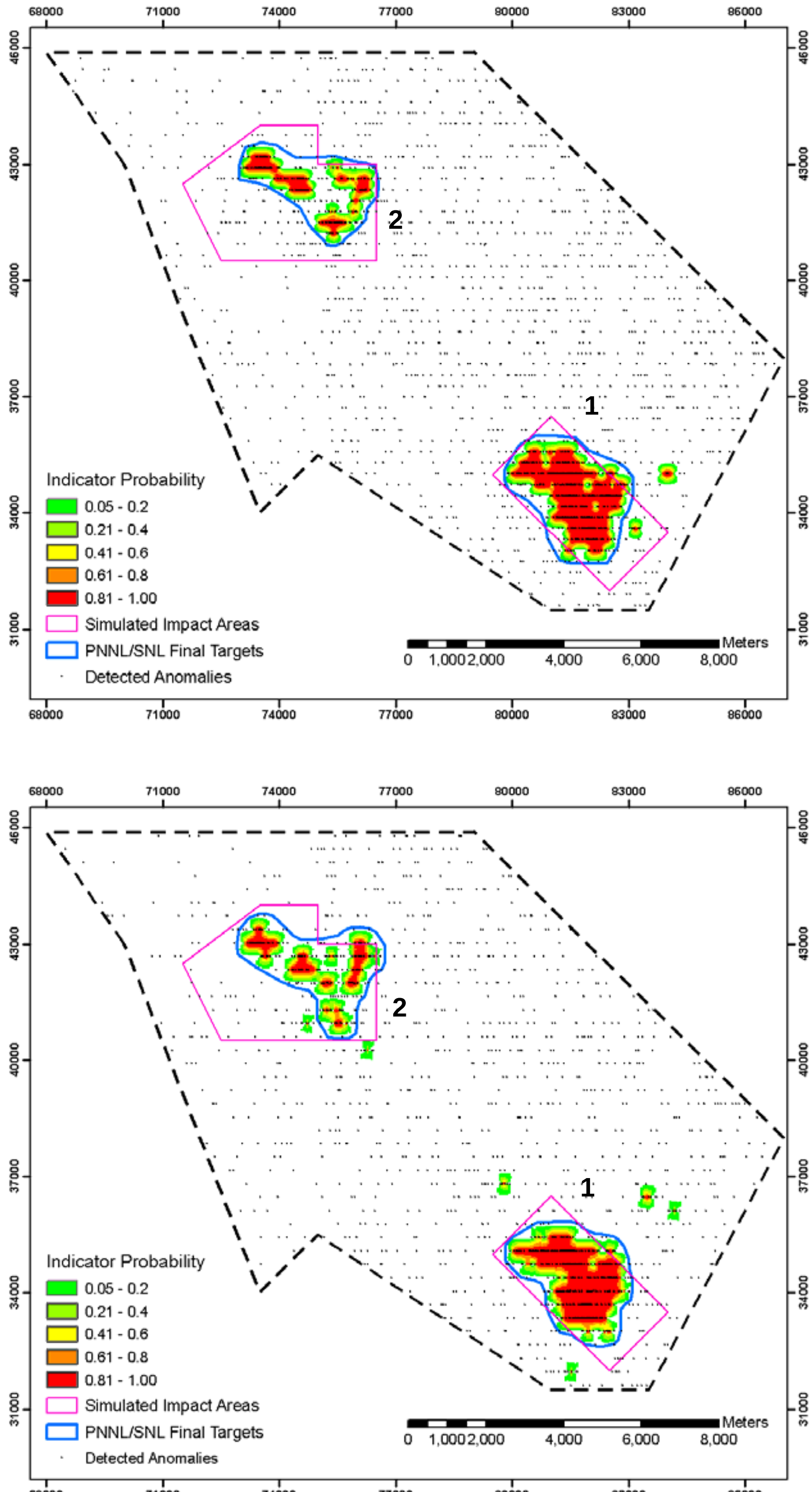
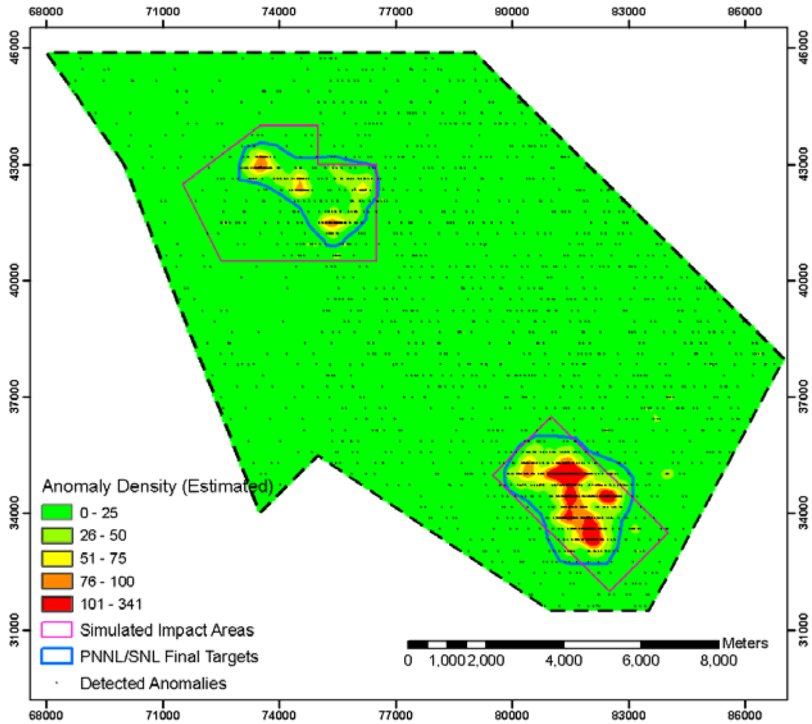


Figure 53: Indicator kriging probability levels for ARA-2B. Top figure shows levels for 282 m spaced transects; bottom figure shows levels for 345 m spaced transects. Numbers indicate final target area identifiers.

Figures 54 and 55 show the kriged estimated anomaly densities and the cell-averaged true anomaly densities for the 282 and 345 m transect sampling scenarios respectively. Both figures show that the kriged estimates represent the actual anomaly density distribution very well. In fact, many of the individual high-density target locations depicted in the actual anomaly plots are easily discernible in the kriged estimates from both sampling scenarios. The very low density targets shown in Figure 50 do not appear in Figure 54 which shows cell-averaged density levels for the kriged density levels and the actual density levels.

The similarity between the actual and estimated anomaly densities are also reflected in comparative box and whisker plots of the data (Figures 56 through 58), and in the descriptive statistics from the data (Table 13). As shown by the comparative box and whisker plots, the interquartile ranges and means of the kriged estimates are very similar to the actual cell-averaged anomaly data. The means from both scenarios differ from the actual mean by less than 9%.

Not surprisingly, the results from the 282 m transect spacing scenario match the characteristics of the original data set more closely than the coarser sampling scenario. The increased sampling of this scenario reduces the difference in mean values between the actual and estimated data sets to less than 3%.



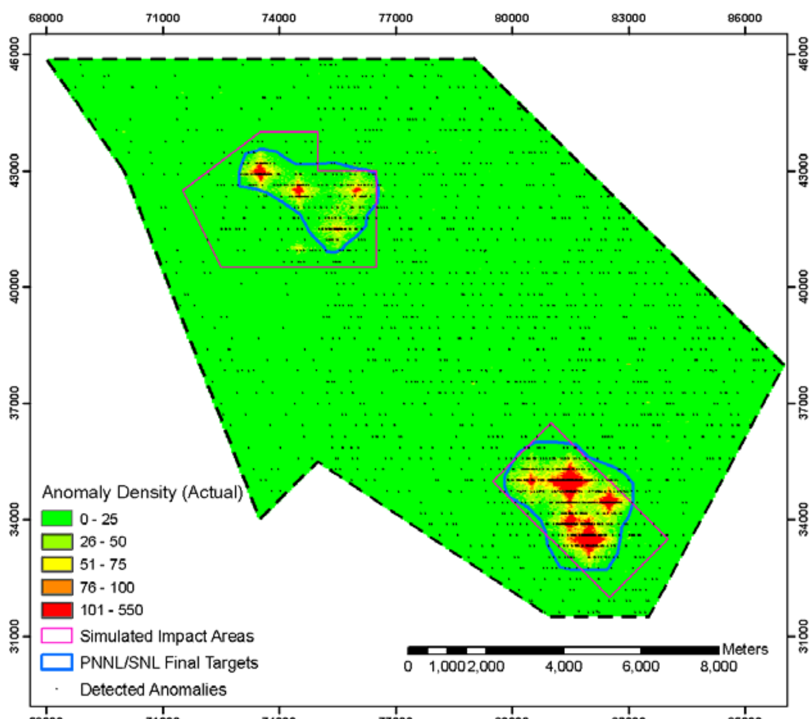


Figure 54: Magnetic anomaly densities in anomalies per acre for ARA-2B. Top figure shows kriged density levels developed using 282 m spaced transects; bottom figure shows actual cell-averaged density levels.

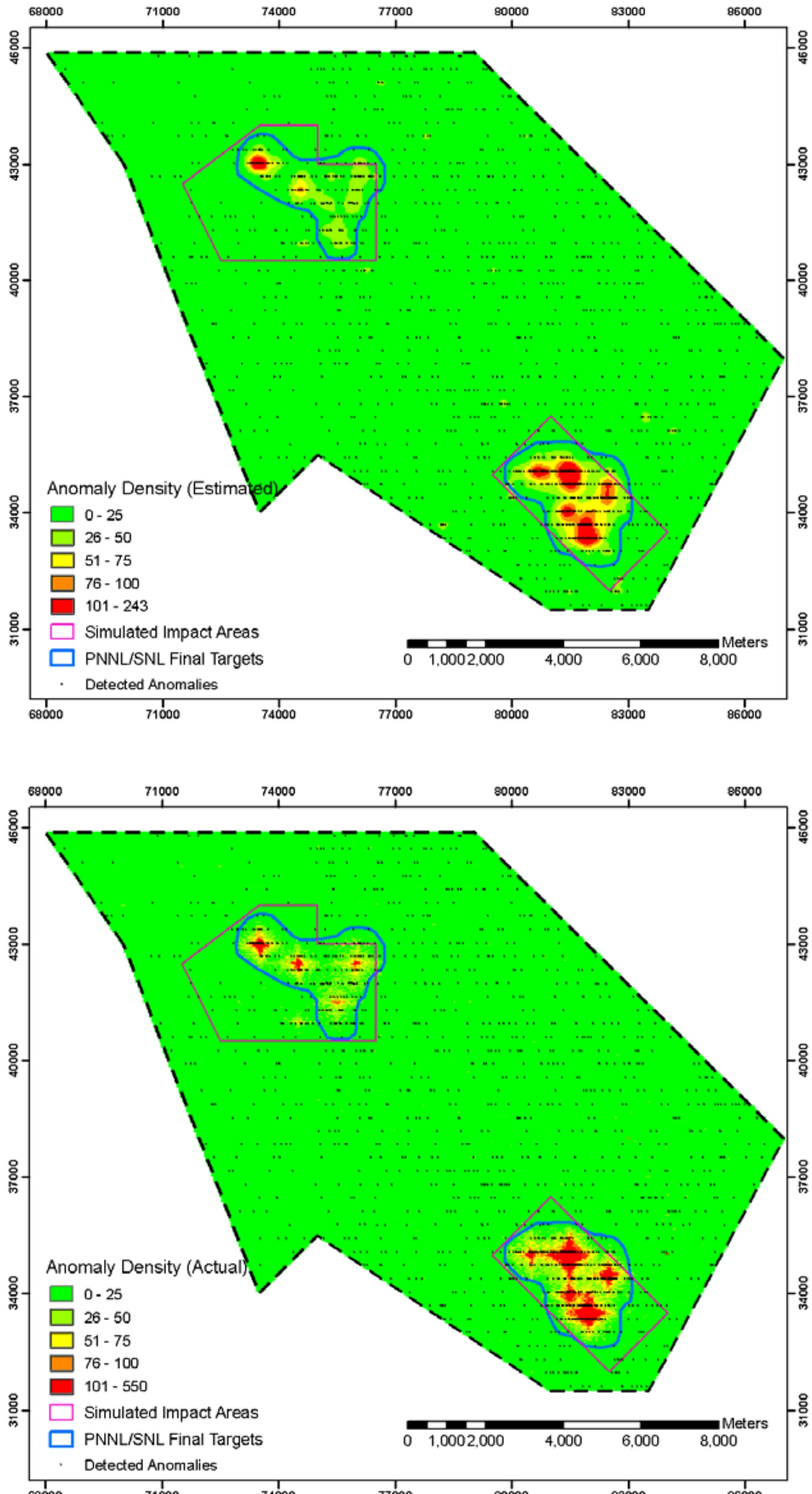
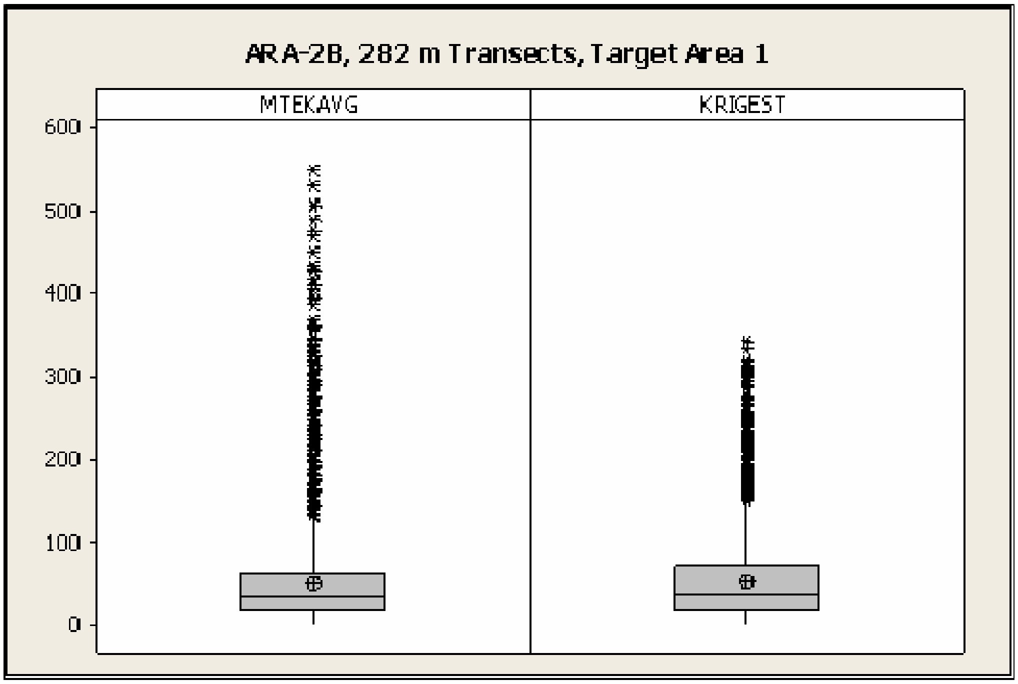


Figure 55: Magnetic anomaly densities in anomalies per acre for ARA-2B. Top figure shows kriged density levels developed using 345 m spaced transects; bottom figure shows actual cell-averaged density levels.



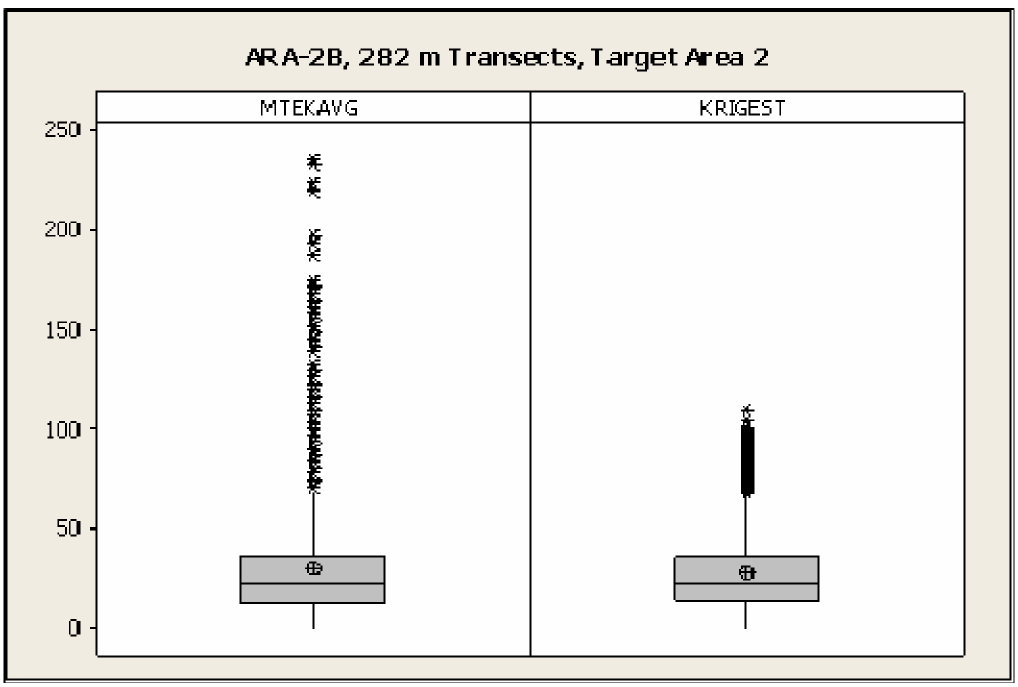
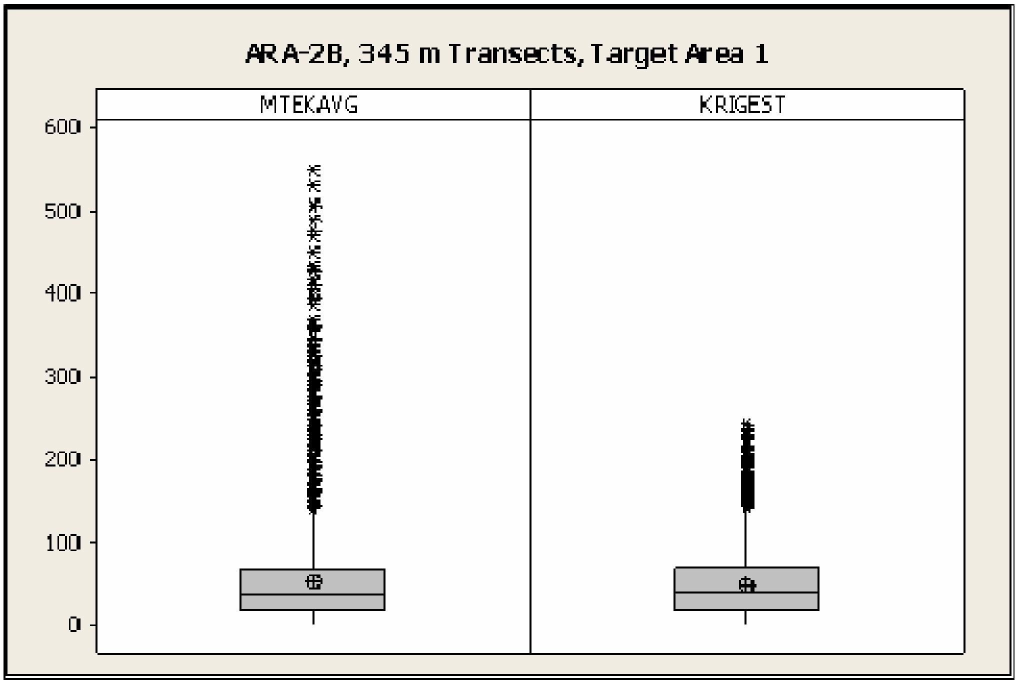


Figure 56: Box and whisker plots for ARA-2B comparing Mitretek range anomaly densities (Mtekavg) and kriging estimated densities (Krigest) for individual target areas. Kriging estimates developed using 282 m spaced transects. Boxes represent interquartile range with median shown by horizontal line. Vertical lines show largest value within upper limit (Q3+1.5(Q3-Q1) and smallest value within lower limit (Q1-1.5(Q3-Q1) outliers beyond this range shown by asterisks. Mean is shown by circle with cross.



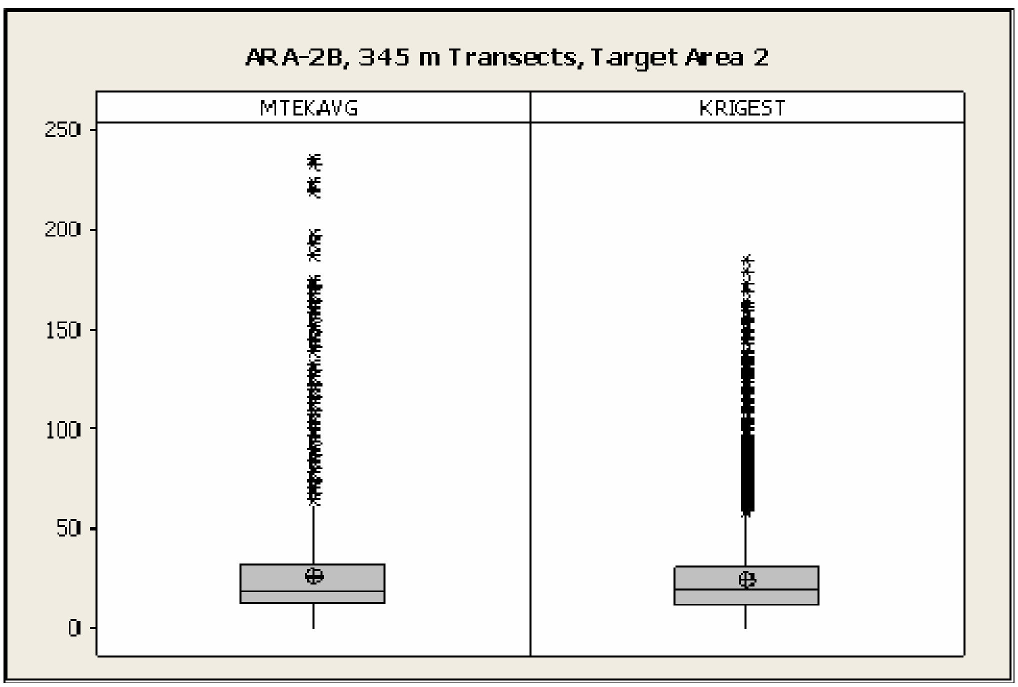
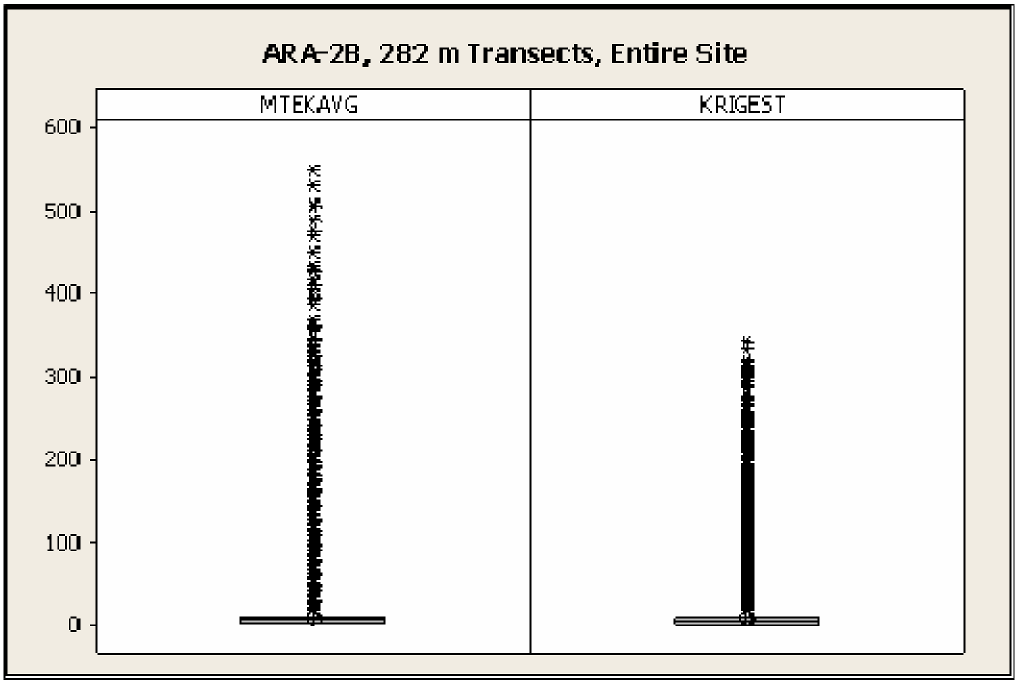


Figure 57: Box and whisker plots for ARA-2B comparing Mitretek range anomaly densities (Mtekavg) and kriging estimated densities (Krigest) for individual target areas. Kriging estimates developed using 345 m spaced transects. Boxes represent interquartile range with median shown by horizontal line. Vertical lines show largest value within upper limit (Q3+1.5(Q3-Q1) and smallest value within lower limit (Q1-1.5(Q3-Q1) outliers beyond this range shown by asterisks. Mean is shown by circle with cross.



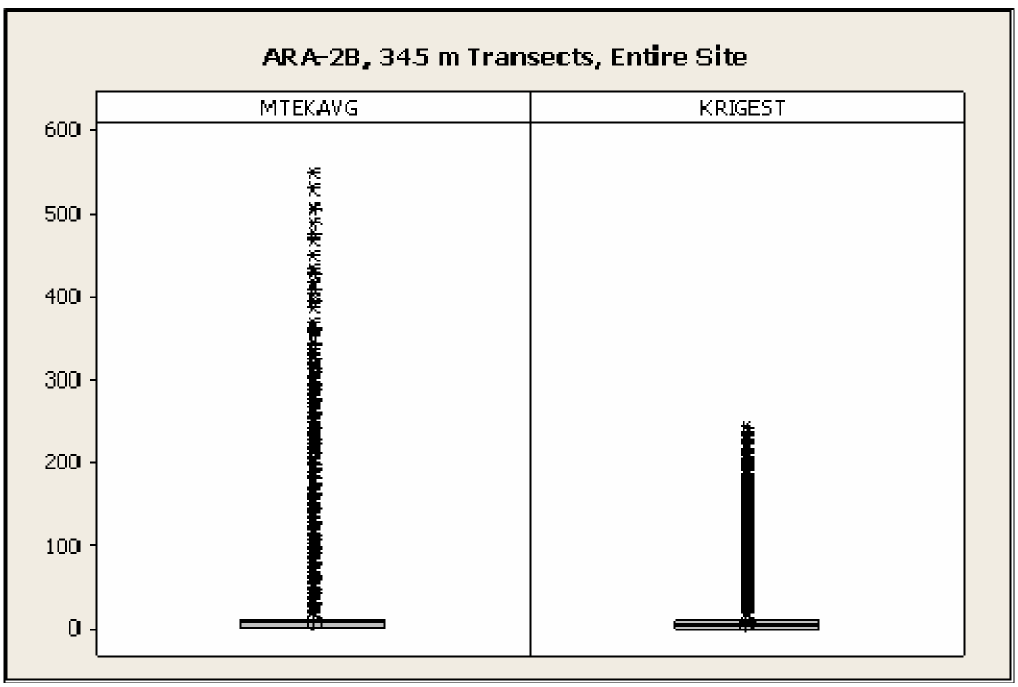


Figure 58: Box and whisker plots for ARA-2B comparing Mitretek range anomaly densities (Mtekavg) and kriging estimated densities (Krigest) for entire range site. Top plot shows kriging estimates developed using 282 m spaced transects; bottom plot shows estimates using 345 m spaced transects. Boxes represent interquartile range with median shown by horizontal line. Vertical lines show largest value within upper limit (Q3+1.5(Q3-Q1) and smallest value within lower limit (Q1-1.5(Q3-Q1) outliers beyond this range shown by asterisks. Mean is shown by circle with cross.

	Area	Source	Mean	Mean Diff.	Std Dev	Min	Max
282 m spaced Transects	Target 1	Mtk	51.4	3.3%	53.5	0	550.4
		KrigEst	53.1		45.8	0	341.0
	Target 2	Mtk	29.5	-5.1%	24.9	0	236.3
		KrigEst	28.0		19.8	0	109.8
	Entire Range	Mtk	8.2	-2.4%	16.7	0	550.4
		KrigEst	8.0		15.5	0	341.0

	Area	Source	Mean	Mean Diff.	Std Dev	Min	Max
345 m spaced Transects	Target 1	Mtk	53.6	-8.2%	54.0	0	550.4
		KrigEst	49.2		38.5	0	242.8
	Target 2	Mtk	26.5	-8.3%	23.9	0	236.3
		KrigEst	24.3		20.3	0	185.0
	Entire Range	Mtk	8.2	-8.5%	16.7	0	550.4
		KrigEst	7.5		13.8	0	242.8

Table 13: Comparison of Kriged estimated (KrigEst) and actual (Mtk) magnetic anomaly densities for ARA-2B range. Estimated anomaly densities were developed using 282 m spaced transects (upper table) and 345 m spaced transects (lower table).

4.3.4 Suspected Range Area 1 (SRA-1)

Suspected Range Area 1 covered 6,200 acres and was used for small arms training. While it is suspected that there were 20mm and 105mm munitions used in this impact area, the transect designs were based the target area assumptions of a 105mm site.

4.3.4.1 SRA-1 Transect Design

The first transect design had a 438 m square grid spacing between each 2 m transect to have a 95% probability of traversing a 398 by 250 m elliptical target area that covered 0.91% of the impact area. The second design was developed to traverse a smaller target than the assumed 105mm target area. This design had a 95% probability of traversing a 198 x 62 m potential target area which resulted in a 204 m square grid spaced transect design that covered 1.94% of the impact area. Figure 59 shows the two transect designs implemented for this area.

4.3.4.2 SRA-1 Target Identification Results

After performing target detection and delineation tests, for both designs, no additional transects were requested and no potential target areas were identified. This was reported to Mitretek and they confirmed that the simulation for this area was designed to have background clutter only but no used targets. Therefore, the PNNL/SNL conclusion that there were no target areas on this site was correct.

The information on the SRA-1 area anomaly distribution as shown in right side of Figure 60 was used to conclude that there were no identifiable target areas. Figure 60 shows the histogram of the window densities that are calculated from a moving window centered on each traversed transect that calculates the density of anomalies per area of transects lying within the user defined radius of the circular window. In comparison, the left side of Figure 60 shows the histogram for the window densities based on ARA-2A where target areas did exist. This histogram shows the combination of the distributional patterns of background with additional distributions based on different target areas that were in ARA-2A (See Section 4.3.2). The histogram from SRA-1 has a much different shape from any of the other impact areas in this simulation because it only identified one distribution instead of a mixture of multiple distributions. The histogram to the right in Figure 60 and the kriged anomaly density maps in Figure 61, which are informative in that they show the type of spatial distribution resulting from a non-use area, signaled that this site did not contain identifiable target areas.

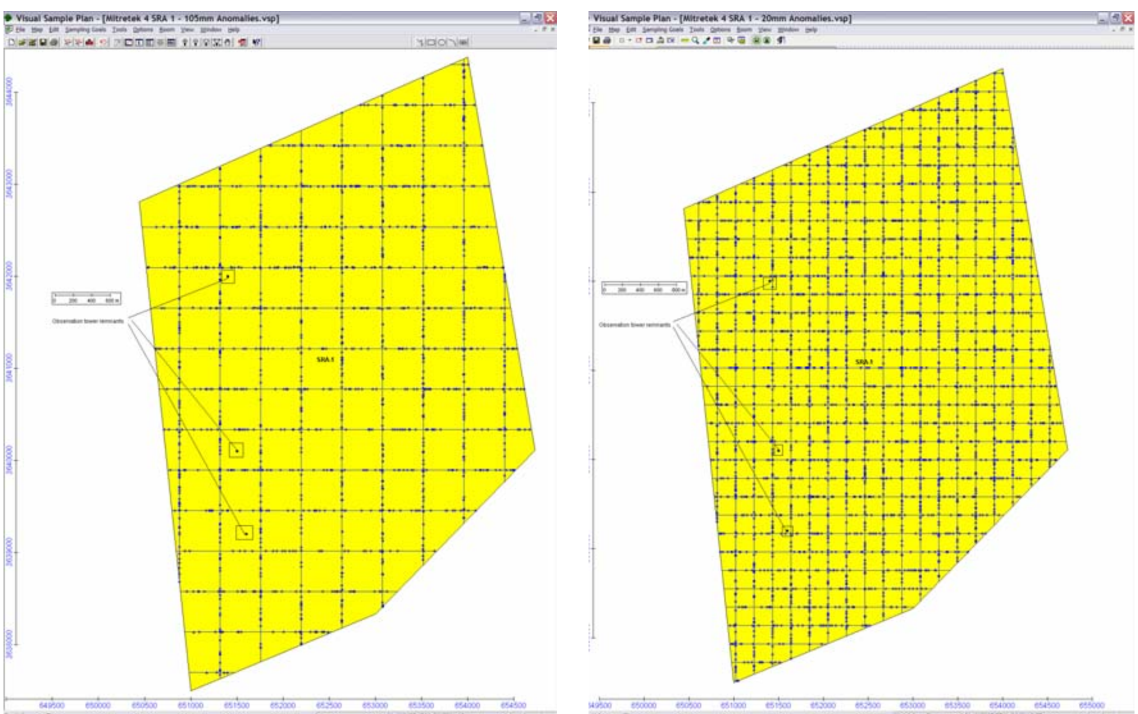


Figure 59: Sparse transect design for SRA-1 based on a 396 by 250 m target area (left) and compact transect design for SRA-1 based on a 198 by 62 m target area (right).

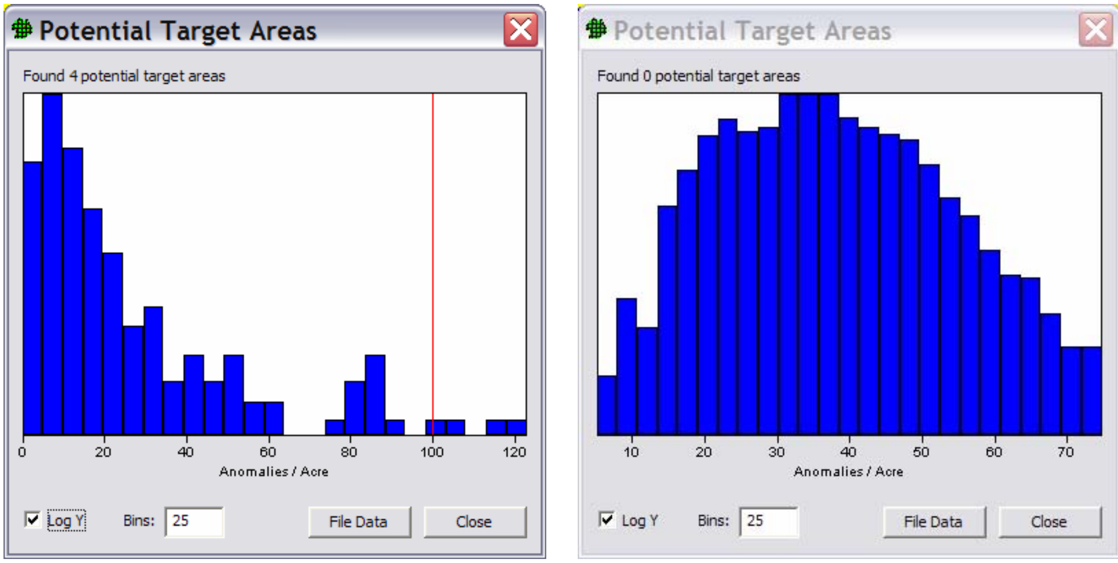


Figure 60: Anomaly density histograms. The histogram to the left is based on the dense transect design scenario in ARA-2A. The histogram to the right is developed using the 20mm SRA-1 scenario.

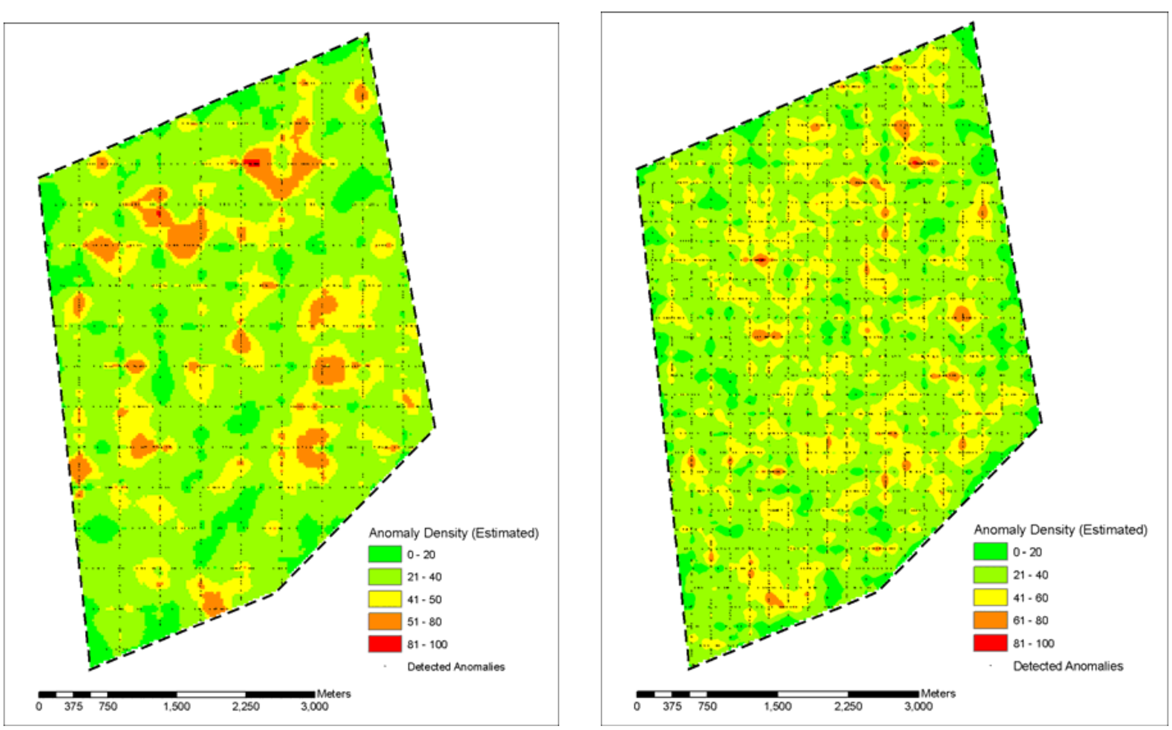


Figure 61: Kriged anomaly density maps in anomalies per acre for SRA-1 site. Left plot created using 438 m spaced transects; right plot created using 204 m spaced transects.

4.3.5 Bombing and Gunnery Range (BGR-1)

The Bombing and Gunnery Range covered 74,650 acres and was the largest impact area with live and dummy munitions used in air-to-ground training. Previous information did indicate that there were potential bomb dumps located in this impact area along with random target areas used for 100, 300, 500, 1000, and 2000 lb. bomb exercises. No specific location information for either the bomb dumps or the targets was provided. Three different scenarios (transect designs) for this impact area were developed. Preliminary results from each design signaled that the assumed target areas were much larger than what had been simulated on the site. Thus scenario 1 was terminated and additional transects over the entire site for scenarios 2 and 3 were requested.

4.3.5.1 BGR-1 Transect Design

Scenario 1 was based on an estimated 2438 by 1625 m elliptical fragment dispersion of a 2000 lb. bomb and a 95% probability of traversing random orientation target areas. Based on the first analysis of the anomaly data observed, it became apparent that the 2 m parallel transects spaced 1989 m apart were too sparse for the identified potential target areas. Those target areas that were identified were definitely much smaller than what was originally assumed under this design scenario. Therefore, no additional work was done for this scenario.

Scenario 2 assumed a 914 by 320 m elliptical fragment dispersion based on a 500 lb. bomb and a 95% probability of traversing random orientation target areas which resulted in 2 m parallel transects spaced 461 m apart. After an initial analysis of the resulting anomaly data, several small target areas were identified so another set of parallel transects spaced 461 m apart were requested to fall between each of the original transects. Thus, the final transect spacing was approximately 230 m apart. The complete set of transects covered 0.86% of the area and is shown in Figure 62 with the identified anomalies.

Scenario 3, shown in Figure 63, was similar to scenario 2 with the exception of assuming that the orientation of the targets was known. The bomb delivery approach was assumed to be parallel to the long axis of the impact area. This change in assumptions resulted in 2 m wide parallel transects spaced 962 m apart. Again, after an initial analysis of the resulting anomaly data, several small target areas were identified so additional 2 m transects spaced 482 m apart which traveled perpendicular to the original transects were requested. The complete transect request covered 1.2% of the impact area (Figure 63).

Figure 62: Scenario 2 transect design. The red lines represent the additional transects requested.

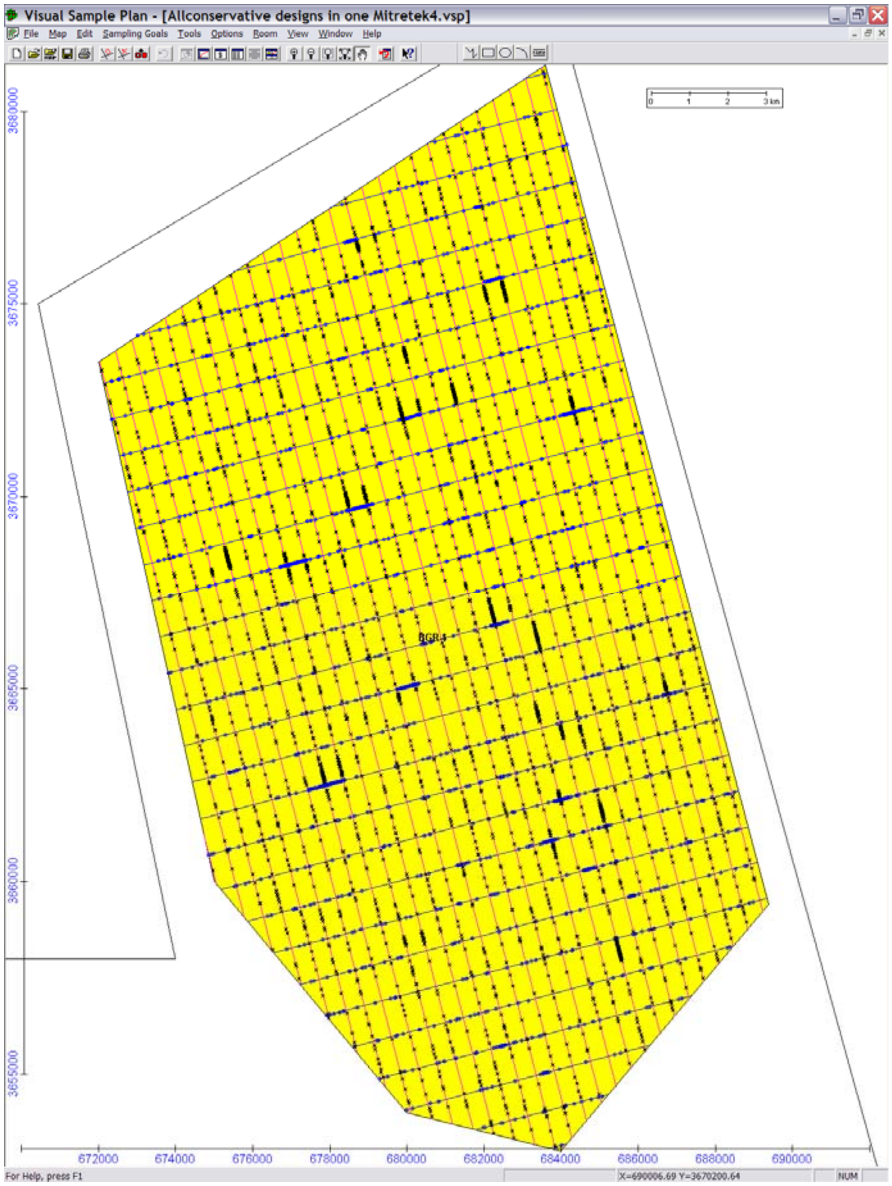


Figure 63: Scenario 3 transect design. The red (north south) lines represent the additional transects requested.

4.3.5.2 BGR-1 Target Area Identification Results

The complete scenario 2 design was used to flag the final potential target areas. Figure 64 shows actual target area sizes colored by their respective densities with the flagged areas and target area perimeter shapes identified. As stated before, the target area shapes were a combination of PNNL's flagging routine and Sandia's target delineation tools. PNNL used a 600 m diameter window with a critical density of 25 anomalies per acre to flag their potential target areas. Similar to the other ranges, Sandia identified their targets using a rectangular averaging window 350 m in length with a width equal to the transect sample width of 2 meters. For its Indicator Kriging analysis, SNL used a critical density of 55 anomalies per acre for scenario 2 of BGR-1.

The final analysis for scenario 3 was based on the rectangular grid transects design. Figure 65 shows the transect design, the actual simulated target areas color coded by density, and the boundaries determined by a combination of PNNL's flagging routine and Sandia's target delineation tools. This design had a transect that passed directly through the middle of the 100 m radius target area. PNNL used a 600 m diameter window and a 40 anomalies per acre critical density to identify the potential target areas. SNL's procedure was similar to that used for scenario 2. A critical density threshold of 55 anomalies per acre was used for the Indicator Kriging.

The actual target area sizes and densities simulated for this impact area were much different than expected. The densities of each target area in BGR-1 range from 48 anomalies per acre to 687 anomalies per acre with a background density of 8.09 anomalies per acre. Thus, this site did not have the difficult task of identifying low density target areas. The unique feature of this site was the varying size of each of the target areas. They ranged from a 600 m radius circle to a 100 m radius circle and there were five targets with a radius smaller than 200 meters. Based on the used transect design there was a high likelihood that it would not traverse the 100 m radius circle with either scenario 2 or 3 transect designs. All target areas that had a diameter larger than the transect design spacing were identified. Figure 66 shows an example of one of the simulated targets in BGR-1 with the blue dots representing UXO placement and Table 14 summarizes the target identification results.

Density of Target Areas above background	Transect Spacing	Percent of Site Covered with Transects	Total Number of Target Areas	Total Number of UXO	Number of Target Areas Identified	Number of UXO Contained	Percent of Target Areas Identified	Percent of UXO Contained
>6	232m	0.86%	24	92049	24	91404	100.00%	99.30%
>6	483m x 961m	1.20%	24	92049	24	92049	100%	100%
<6	483m x 961m	1.20%	No target areas with density less than 6 per acre.					
<6	232m	0.86%	No target areas with density less than 6 per acre.					

Table 14: Summary of the BGR-1 Target Area Identification Results

Figure 67 shows the indicator kriging probability levels for BGR-1 scenarios 2 and 3 using indicator kriging thresholds of 55 anomalies per acre for both scenarios. Only areas with a probability of 0.05 or greater are shown by color-filled contours. These areas were included as part of the information used in determining the final target boundaries. Variogram model parameters used in the kriging estimates are listed in Appendix A.

As seen in Figure 67, the results from both sampling designs are similar. The major difference between the target delineations from the two scenarios is a single target area identified in scenario 3 that was not detected in scenario 2. Figures 68 and 69 present kriging estimates of anomaly densities for scenarios 2 and 3 respectively. The cell averaged actual anomaly densities for BGR-1 are also presented for comparison. As

Figures 68 and 69 show, the kriged estimates of anomaly densities developed from the limited transect data closely match the spatial distribution of the actual anomaly data set.

Figure 64: BGR-1 Scenario 2 transect design with flagged areas of concern, joint PNNL/Sandia target area perimeters, and simulated target areas colored by density above background

Figure 65: BGR-1 Scenario 3 transect design with flagged areas of concern, joint PNNL/Sandia target area perimeters, and simulated target areas colored by density above background

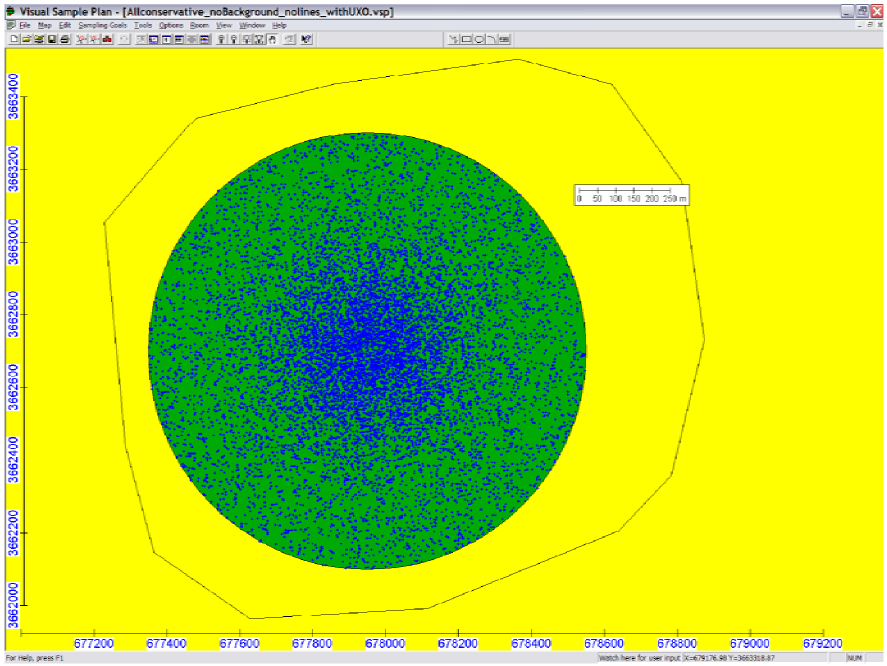


Figure 66: Example of UXO placement in BGR-1 simulated target areas. The green circle represents the simulated target area boundary and the black line represents the perimeter delineation.

Tables 15 and 16 present summary descriptive statistics for the BGR-1 range and each of the identified target areas for scenarios 2 and 3 respectively. As shown by these tables, the difference in the means between actual and estimated anomaly densities is less than 3% for the entire site for each scenario. However, the difference in means for individual target areas was as high as 38% for scenario 2 and 56% for scenario 3.

Further investigation into the areas with large differences between the estimated and actual anomaly densities revels that these discrepancies are primarily due to the small size of the actual target areas with respect to the sample transect spacing. For example, target area 6 had the largest difference in means for scenario 3 (55.6%) but a much smaller difference for scenario 2 (11.5%). Three of the sampling transects for scenario 2 passed through the actual fragmentation area for that target, whereas only one of the transects from scenario 3 sampled the actual target area. A similar pattern is seen in the other target areas with large differences in the means.

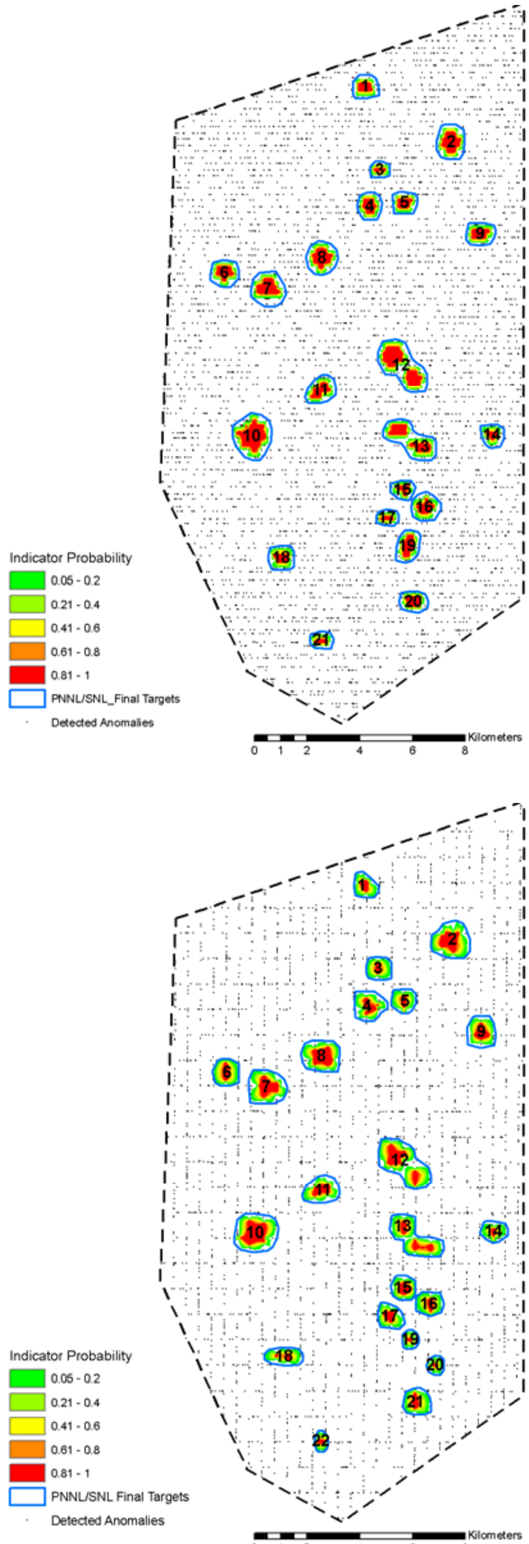
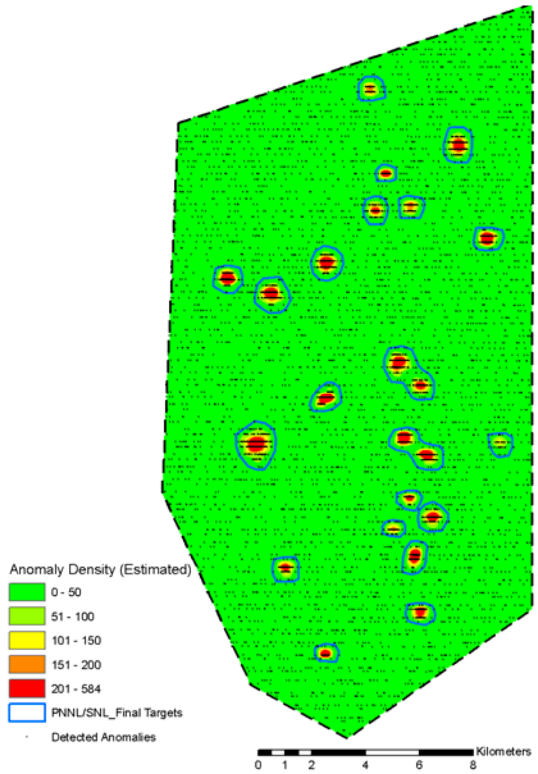


Figure 67: Indicator kriging probability levels for BGR-1. Top figure shows levels for scenario 2; bottom figure shows levels for scenario 3. Numbers indicate final target identifiers. Maps rotated from original coordinate system.



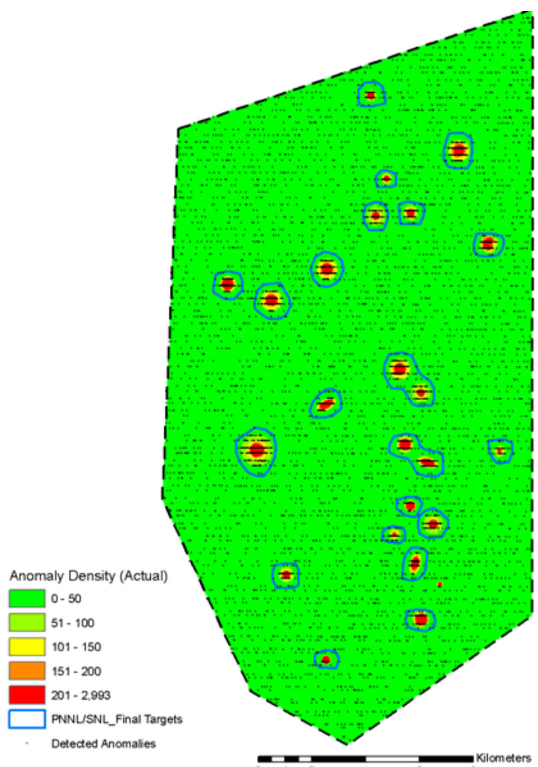
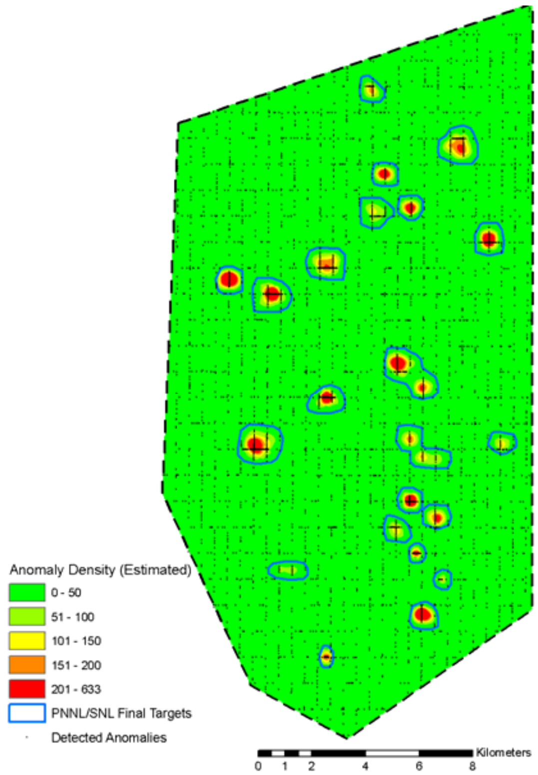


Figure 68: Magnetic anomaly densities in anomalies per acre for BGR-1. Top figure shows kriged density levels for scenario 2; bottom figure shows actual cell-averaged density levels. Maps rotated from original coordinate system.



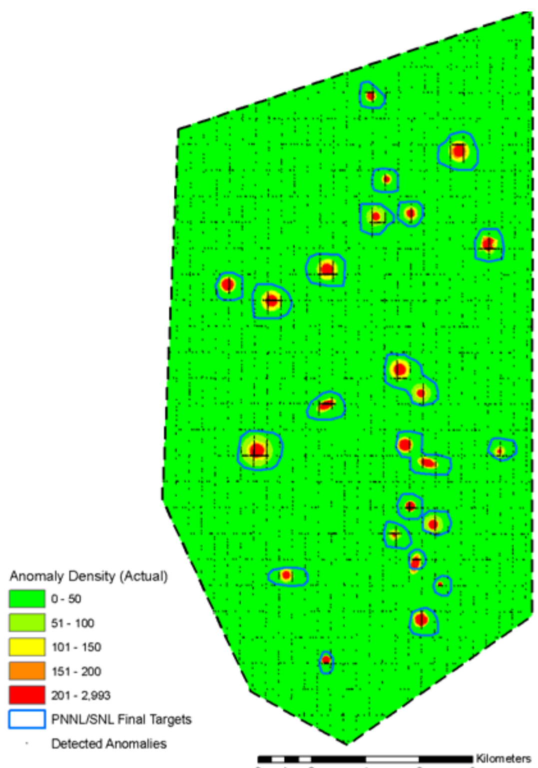


Figure 69: Magnetic anomaly densities in anomalies per acre for BGR-1. Top figure shows kriged density levels for scenario 3; bottom figure shows actual cell-averaged density levels. Maps rotated from original coordinate system.

Area	Source	Mean	Mean Diff.	Std Dev	Min	Max
Target 1	Mtk	51.0	7.8%	134.9	0	1617.1
	KrigEst	55.0		55.9	0	222.4
Target 2	Mtk	88.4	-12.0%	171.0	0	2734.1
	KrigEst	77.8		79.4	0	301.6
Target 3	Mtk	65.4	37.5%	123.3	0	830.4
	KrigEst	89.9		104.7	0	399.1
Target 4	Mtk	70.3	-1.7%	83.2	0	464.6
	KrigEst	69.1		64.4	0	285.0
Target 5	Mtk	63.4	-3.0%	92.1	0	464.6
	KrigEst	61.5		56.7	0	225.7
Target 6	Mtk	92.4	11.5%	167.6	0	916.2
	KrigEst	103.0		134.9	0	583.6
Target 7	Mtk	79.4	-1.6%	137.5	0	861.2
	KrigEst	78.1		94.7	0	461.1
Target 8	Mtk	90.7	-7.4%	145.0	0	893.6
	KrigEst	84.0		98.6	0	420.2
Target 9	Mtk	90.9	7.8%	127.1	1.6	600.6
	KrigEst	98.0		108.1	0	412.6
Target 10	Mtk	81.1	10.0%	109.0	0	642.6
	KrigEst	89.2		100.4	0	487.0
Target 11	Mtk	76.3	21.4%	159.4	0	1138.0
	KrigEst	92.6		128.2	0	573.5
Target 12	Mtk	71.3	3.8%	117.2	0	874.1
	KrigEst	74.0		82.9	0	391.3
Target 13	Mtk	85.6	2.7%	165.4	0	1178.5
	KrigEst	87.9		110.9	0	501.5
Target 14	Mtk	45.2	-8.6%	44.4	0	244.4
	KrigEst	41.3		31.0	5.4	148.0
Target 15	Mtk	97.2	-36.8%	221.7	1.6	1701.3
	KrigEst	61.4		71.7	0	283.0
Target 16	Mtk	69.1	11.3%	110.1	0	937.3
	KrigEst	76.9		83.8	0	367.3
Target 17	Mtk	57.9	10.5%	48.6	4.9	249.3
	KrigEst	64.0		48.2	6.9	197.7
Target 18	Mtk	56.0	19.6%	87.3	0	461.3
	KrigEst	67.0		69.1	0.4	291.3
Target 19	Mtk	78.9	17.4%	162.3	0	118.6
	KrigEst	92.6		116.8	0	487.7
Target 20	Mtk	114.4	-32.1	186.3	0	953.4
	KrigEst	77.7		80.5	0	281.3
Target 21	Mtk	107.4	-18.6	313.3	0	2993.1
	KrigEst	87.7		107.3	0	422.0
Entire Range	Mtk	12.7	1.6%	39.97	0	2993.06
	KrigEst	12.9		29.62	0	583.60

Table 15: Comparison of Kriged estimated (KrigEst) and actual (Mtk) magnetic anomaly densities for BGR-1 range scenario 2.

Area	Source	Mean	Mean Diff.	Std Dev	Min	Max
Target 1	Mtk	53.0	6.6%	137.9	0	1617.1
	KrigEst	56.5		56.9	0	222.4
Target 2	Mtk	66.8	-11.4%	150.7	0	2734.1
	KrigEst	59.2		74.7	0	301.6
Target 3	Mtk	40.5	35.1%	96.9	0	830.4
	KrigEst	54.7		88.3	0	399.1
Target 4	Mtk	51.7	-20.3%	75.4	0	464.6
	KrigEst	41.2		31.1	0	146.6
Target 5	Mtk	61.1	38.3%	90.8	0	464.6
	KrigEst	84.5		84.2	0	343.8
Target 6	Mtk	95.7	55.6%	170.2	0	916.2
	KrigEst	148.9		143.9	0	580.4
Target 7	Mtk	69.7	16.5%	130.1	0	861.2
	KrigEst	81.2		103.3	0	574.5
Target 8	Mtk	72.3	-4.1%	132.5	0	893.6
	KrigEst	69.3		58.7	0	227.6
Target 9	Mtk	68.4	37.9%	114.8	0	600.6
	KrigEst	94.3		124.8	0	633.0
Target 10	Mtk	79.9	2.1%	105.7	0	642.6
	KrigEst	81.6		90.4	0	473.8
Target 11	Mtk	65.3	19.6%	148.2	0	1138.0
	KrigEst	78.1		122.0	0	573.5
Target 12	Mtk	70.1	6.6%	116.5	0	874.1
	KrigEst	74.7		84.2	0	436.3
Target 13	Mtk	85.5	1.6%	165.3	0	1178.5
	KrigEst	86.9		111.3	0	501.5
Target 14	Mtk	42.1	8.1%	45.3	0	244.4
	KrigEst	45.5		33.5	5.8	159.8
Target 15	Mtk	73.6	-37.1%	194.0	1.6	1707.3
	KrigEst	46.3		66.5	0	283.0
Target 16	Mtk	79.9	-8.4%	117.3	0	937.3
	KrigEst	73.2		63.6	0.1	265.0
Target 17	Mtk	39.0	16.2%	43.3	0	249.3
	KrigEst	45.3		36.0	0.4	143.9
Target 18	Mtk	53.2	-44.4%	85.2	0	461.3
	KrigEst	29.6		18.3	0.7	73.7
Target 19	Mtk	159.9	9.4%	227.7	1.6	1118.6
	KrigEst	175.0		140.4	6.0	487.7
Target 20	Mtk	33.6	-49.1%	108.9	0	1044.1
	KrigEst	17.1		12.0	0	42.0
Target 21	Mtk	92.5	25.6%	171.4	0	953.4
	KrigEst	116.2		125.1	0.4	506.6
Target 22	Mtk	155.6	-27.6%	372.7	0	2993.1
	KrigEst	112.6		121.9	0	422.0
Entire Range	Mtk	12.7	2.4%	42.1	0	2993.1
	KrigEst	13.0		31.1	0	583.6

Table 16: Comparison of Kriged estimated (KrigEst) and actual (Mtk) magnetic anomaly densities for BGR-1 range scenario 3.

5. Summary of Data Analysis, Interpretation and Evaluation for the SimRangE 4 Simulation

Ordnance operations were simulated on five different ranges by Mitretek and the results of these simulations were kept from the PNNL/Sandia statistical site characterization design tools team. For each of the simulated ranges, the suspected ordnance types were provided to the characterization design team, and for one of the ranges a suspected location and target diameter were also provided. Based on this information, the PNNL/SNL team assumed various conceptual site models (CSM) for each range and requested geophysical sampling transects where the transect designs were based on each CSM. The locations of the geophysical anomalies along the requested transects was provided back to the PNNL/SNL team by Mitretek. Based on these results, target boundaries and anomaly density maps were created. In some cases, additional transects were requested to better define the existence and/or the extent of suspected target areas.

5.1 Data Analysis Results

The performance of the PNNL/SNL methods was excellent with 100% of the UXO and 100% of the target areas that had a density as low as 6 anomalies per acre above background identified (with the exception of the sparse BGR-1 design). One target area in the BGR-1 impact area had a diameter of 200 m. Even though the transect spacing for both BGR-1 designs were spaced farther apart than the 200 m diameter target area, one of the two transect designs did identify this target area.

With exception to ARA-1, all of the impact areas had a sparse and a dense transect design. The multiple transect designs were created to show the sensitivity of target identification to transect spacing. Due to the large differences in assumed target area sizes to the simulated target area sizes, ARA-2B and BGR-1 transect designs did not provide the type of scenarios where this sensitivity could be examined. SRA-1 had two transect designs but no targets were located in this impact area and only one transect design was requested for ARA-1. However, ARA-2A did provide differing results on the simulated targets based on the transect design. It is not clear that the differing results for the Ft. Ritchie target data were a result of the transect design or the unique way in which these data were applied to the site. ARA-2A showed that the tighter 1 m transects did not perform as well as the slightly sparser 2 m transects. Figure 32 showed the power curves that help explain these results. For the ARA-2A site, the Ft. Ritchie data was reported separately and will not be included in the combined summary tables (Tables 13 and 14).

Overall, the kriged estimates of magnetic anomaly densities compared well with the true density values. For those target areas delineated in ranges ARA-1, ARA-2A and ARA-2B, for all scenarios, the average value of the absolute values of mean difference between the true and estimated anomaly densities was only 7.6%. This value drops to 3.5% when computed using range-wide mean difference values. These values indicate that the estimated anomaly densities matched the true density values closely for these ranges.

BGR-1 contains the delineated target areas with the largest differences in means of anomaly densities for the delineated target areas. Scenario 2 for BGR-1 contained 21 identified target areas, 4 of these had mean differences between the true and estimated magnetic anomaly densities that exceeded 20%. Scenario 3 for BGR-1 contained 22 identified target areas, 10 of which had mean differences exceeding 20%. The average value of the absolute values of the mean differences for the delineated target areas is 13.5% for scenario 2 and 21% for scenario 3. The spatial characteristics of the small, high-density targets of BGR-1 were not well represented by the coarser spacing of the Scenario 3 transects. This lead to the situation where, although the targets were detected, the compact spatial structure of the targets could not be recreated through the limited transect data. Additional transect data would be necessary to accurately reflect the spatial structure of the relatively small targets contained in BGR-1.

Overall, the results from the magnetic anomaly density mapping exercise show, that with only limited transect information, reliable estimates of the magnetic anomaly densities can be developed. A majority of the identified target areas had mean values of anomaly density that differed from the true value by less than 20%. Although the means of some of the identified targets in BGR-1 had differences greater than 20%, the general pattern of the true anomaly distributions were well represented.

The final summary is based on the most conservative designs for each impact area. Table 17 summarizes the results for each scenario based on target areas that had a density greater than 6 anomalies per acre above background and Table 18 contains the demonstration performance objectives.

Impact Area	Transect Spacing	Density of Target Areas above background	Percent of Site Covered with Transects	Total Number of Target Areas	Total Number of UXO	Number of Target Areas Identified	Number of UXO Contained	Percent of Target Areas Identified	Percent of UXO Contained
ARA-2B	282m	>6	0.71%	9	253	9	253	100.00%	100.00%
ARA-2A	344m	>6	0.60%	3	175	3	175	100.00%	100.00%
SRA-1	204m x 204m	>6	1.94%	None	None	None	None	Correct	Correct
ARA-1	344m	>6	0.66%	7	110	7	110	100.00%	100.00%
BGR-1	483m x 961m	>6	1.20%	24	92049	24	92049	100.00%	100.00%
ARA-2B	282m	<6	0.71%	8	19	1	0	12.50%	0.00%
ARA-2A	344m	<6	0.60%	2	38	1	27	50.00%	71.05%
SRA-1	204m x 204m	>6	1.94%	None	None	None	None	Correct	Correct
ARA-1	344m	<6	0.66%	5	73	1	31	20.00%	42.47%
BGR-1	483m x 961m	<6	1.20%	No target areas with density less than 6 per acre.					

Table 17: Target identification and UXO containment performance of PNNL/Sandia for the conservative designs separated by target density

Type of Performance Objective	Primary Performance Criteria	Expected Performance	Performance Confirmation Method	Actual Performance
Quantitative	% of UXO encompassed with suspected bounded areas	100% unless in completely inaccessible areas	Compared to actual simulated targets	See Table 17
	% of Target areas identified within suspected bounded areas	100% unless in completely inaccessible areas	Compared to actual simulated targets	See Table 17
	% of UXO encompassed within suspected bounded areas if target density is greater than 6 anomalies per acre above background.	100% unless in completely inaccessible areas	Compared to actual simulated targets	100%
	% of Target areas identified with suspected bounded areas if target density is greater than 6 anomalies per acre above background.	100% unless in completely inaccessible areas	Compared to actual simulated targets	100%
	Accurate distinction between target areas and high density non-OE related areas.	No non-target areas flagged as target areas	Compared to actual simulated targets	100%
	% of land area covered by transects	<10%	Designed	0.6% - 1.94%
	Accurate estimate of anomaly density for each suspected target area	Within 20%	Compared to actual simulated targets	Non-BGR sites: 7.6% BGR: 21%
Qualitative	Minimal amount of area outside of true target areas included in bounded suspected target areas.	Minimize	Compared to actual simulated targets	Minimized

Table 18: Performance objective results for the PNNL/Sandia team

5.2 Issues Associated with Simulated Sites Anomaly Distributions

During the course of this exercise, a number of inconsistencies between the transect data and the conceptual site models were noticed. At the conclusion of the exercise, when all of the simulated data were provided to the PNNL/Sandia team by Mitretek for a "post-mortem" analysis, the causes of these inconsistencies and their full impact on the characterization process and conclusions drawn from the characterization data were made clear. The significant inconsistencies in the simulated data are highlighted below and then examined in detail in Appendix B at the end of this report.

- The simulated 4.2" mortar target areas seemed to be much larger than standard 4.2" mortar target areas.
- The simulated bombing range target areas in BGR-1 were much smaller than the assumed munitions would indicate.
- The dispersion of the 4.2" mortar target areas seem to have a peculiar "cross" pattern where the anomaly density is highest along the north-south and east-west axes of the target area.
- The BGR-1 site had target areas with a high percentage of UXO in relation to ordnance fragments (27%) in each target area
- The UXO in the BGR-1 site was uniformly spread throughout the entire target area. Under standard assumptions the UXO is contained in the area where the munitions would land (Inside the range and deflection probable errors--R_{pe} and $D_{pe.}$) not among the outer locations of the fragments.
- The Ft. Ritchie "real" data as applied in this simulation did not provide information about the location of non-surveyed parking lots and buildings. Transects that covered parking lots and buildings were reported to the PNNL/Sandia team as no anomalies found instead of not able to perform desired transects.
- The background level for the western area of ARA-2B was 2 anomalies per acre and did not follow the assumed uniform distribution of background used throughout this simulation.

6. Bibliography

Casella, G., and R. L. Berger. 1990. *Statistical Inference*. Wadsworth, Beaumont, CA.

Gilbert, R.O., Version 2.0 *Visual Sample Plan (VSP): UXO Module Code Description and Verification.* PNNL-14267. Pacific Northwest National Laboratory, Richland, WA. April 2003.

Grieve, A.P. 1994. “A Further Note on Sampling to Locate Rare Defectives with Strong Prior Evidence,” *Biometrika* 81(4): 787-789.

Hassig, N.L., J.E. Wilson, R.O. Gilbert, B.A. Pulsipher, L.L. Nuffer. 2005. *Visual Sample Plan Version 4.0 User's Guide*. PNNL-15247. Pacific Northwest National Laboratory, Richland, Washington.

O’Brien, R. F. 2002. *Probabilities of a Grid of Rectangular Transects of Positive Width Intersecting an Elliptical Target*. PNNL-13868. Pacific Northwest National Laboratory, Richland, Washington.

Pulsipher, Brent A, S.A. McKenna, C.A. McKinstry. 2005, *Demonstration Plan for Statistical Methods and Tools for UXO Site Characterization on Final Simulated Site,* PNNL-15608 , Pacific Northwest National Laboratory, Richland, Washington.

Saito, H., S.A. McKenna, D.A. Zimmerman and T.C. Coburn, 2005, Geostatistical Interpolation of Object Intensities Collected from Multiple Finite Transects, *Stochastic Environmental Research and Risk Assessment*, 19, pp. 71-85, DOI: 10.1007/s00477-004-0207-3

Simmons, M. 2003. *SimRangE Development and Analysis Plan (Final Draft)*, Mitretek Technical Report, Mitertek Systems, Inc. Falls Church, Virginia

Wright, T. 1992. “A Note on Sampling to Locate Rare Defectives with Strong Prior Evidence,” *Biometrika* 79(4):685-691

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(Other sections not applicable: Cost Assessment and Implementation Issues)

Appendix A

Variogram Parameters

This Appendix contains an explanation and listing of the various parameters used in modeling the variograms for each of the range scenarios for which kriging estimates were developed.

Variograms display how the variance between data points separated by a particular distance changes as that distance increases. Typically this separation based variance increases as the separation distance, or lag, increases. Figure 1A shows typical parameters used in modeling variograms.

Commonly, the variance values in a variogram level off after reaching some separation distance. The distance at which the variance tends to level off is referred to as the range of the variogram model. The variance at which the variogram levels off is termed the sill. In some cases, the experimental variogram data will display some variance even at a zero separation distance. If this is the case, then this is modeled by an initial variance value referred to as the nugget.

Separate variogram models were developed for each of the kriging estimate scenarios presented in the main text. The parameters of these models are presented in Tables A1 and A2.

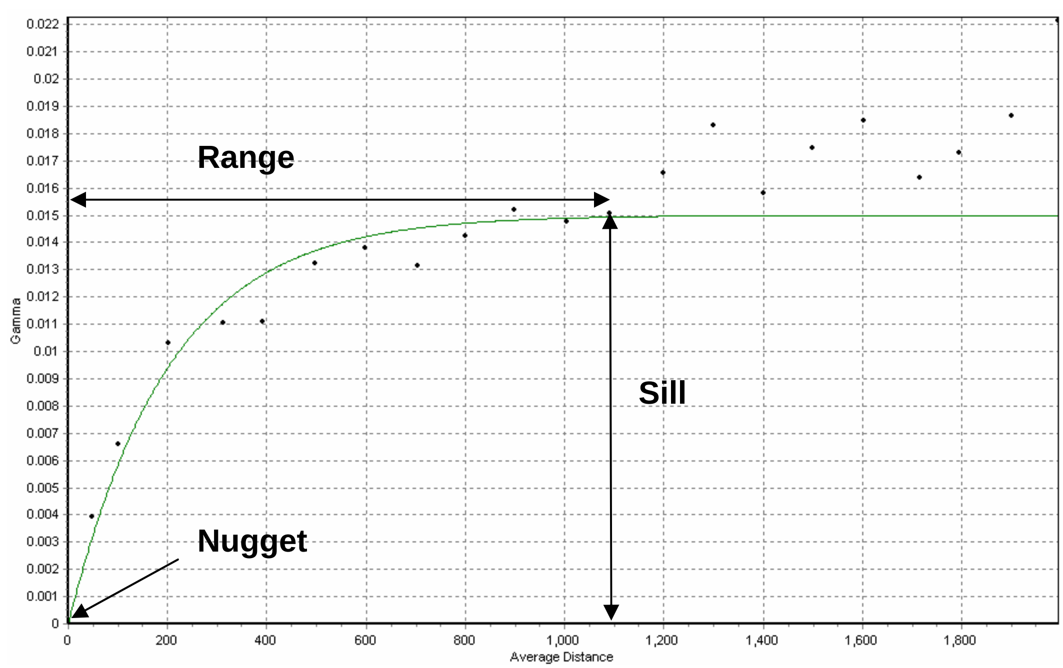

Figure A1: Example variogram showing parameters used for model specification. Example shown is indicator variogram using a threshold of 65 anomalies per acre for ARA-1. Points represent values computed from transect data; solid lines represent models fit to data points.

Site	Transect Spacing (m)	Model Type	Nugget	Sill	Range (m)
ARA-1	344	Ex	0	0.015	610
ARA-2A	298	Ex	0	0.026	1200
ARA-2A	344	Sp	0	0.017	920
ARA-2B	345	Ex	0	0.008	500
		Sp	0	0.034	2500
ARA-2B	282	Ex	0	0.008	500
		Sp	0	0.034	2500
SRA-1	438	Ex	0	0.0445	215
SRA-1	204	Ex	0	0.037	250
BGR-1	230	Sp	0	0.028	900
BGR-1	961/483	Sp	0	0.03	890

Table A1: Variogram model parameters used for Indicator Kriging for each range scenario. Model types are given as: Ex=exponential and Sp=Spherical. Multiple lines per scenario indicate a compound model was used. All models were isotropic.

Site	Transect Spacing (m)	Model Type	Nugget	Sill	Range (m)
ARA-1	344	Sp	0	120	430
		Ex	0	100	4000
ARA-1	(6 transects)	Ex	0	127	900
ARA-1 (residuals)	(6 transects)	Sp	0	470	2300
ARA-2A	298	Sp	0	350	1000
ARA-2A	344	Sp	0	235	900
ARA-2B	345	Ga	0	95	800
		Sp	0	240	2500
ARA-2B	282	Ga	0	95	800
		Sp	0	240	2500
SRA-1	438	Ex	0	215	235
SRA-1	204	Ex	0	210	340
BGR-1	230	Sp	0	710	1250
BGR-1	961/483	Sp	0	760	1400

Table A2: Variogram model parameters used for anomaly density Kriging for each range scenario. Model types are given as: Ex=exponential, Ga=Gaussian, and Sp=Spherical. Multiple lines per scenario indicate a compound model was used. All models were isotropic.

Appendix B

Issues Associated with Simulated Sites Anomaly Distributions

Following the final target delineation, PNNL and SNL were provided with the magnetic anomaly data that were used to represent the simulated sites. These data were provided to the site characterization team to be used in a very detailed assessment of the results of the site characterization activities. Typically these data consisted of X and Y coordinate values for each simulated anomaly. The simulated anomalies were typically grouped as general background clutter, munitions fragments, or actual UXO.

Upon review of these data, various irregularities were noticed in the anomaly data. Here, irregularities refer to conditions where the simulated anomalies are significantly different from what would typically be expected for the type of site or process being simulated.

For simulated ranges ARA-1, ARA-2A, and ARA-2B irregularities were seen in the distribution of munitions fragments for each of the target areas. Figures B1 through B3 show examples of the patterns of munitions fragments observed for these ranges. Most notable from these examples are the rectangular footprint described by the anomaly distribution for each target, and the cross-shaped pattern created by higher density areas oriented in a north-south, east-west configuration centered on each individual target. These patterns are unexpected for explosive fragmentation and are not explained by the firing point to target alignment as all targets have the north-south and east-west orientations regardless of the relative orientation between the target and the firing location. This type of pattern was not observed in the BGR-1 anomaly data. The impact of this anomaly pattern on the transect sampling results is not clear. The cross pattern increases the anomaly density along the central axes of the target, but at the cost of decreasing density everywhere else. This would tend to increase potential recognition of the site as an area with anomaly densities above the general clutter, but may have a negative impact on recognizing the area as a target because the area of higher densities is reduced from what would be expected. A transect crossing one arm of the cross pattern might show high density results only at the arm itself, which may result in the target not being recognized. Conversely, the higher-density arms my aid in the recognition of very low density targets. Determining the actual impact of this irregularity requires analysis of the contrast between the target and background clutter densities on a case-by-case basis. In all cases, the unusual anomaly patterns for these targets would have a direct impact on the shape of the target boundaries delineated from the transect data.

For simulated range ARA-2A, data from a field investigation conducted at Fort Ritchie were included in the magnetic anomaly data set. Figure B4 shows the distribution of these data. There are two irregularities associated with this data set. First is that the distribution of anomalies in the eastern half of the data set contains many apparent blank areas. These are apparently due to areas at Fort Ritchie that were not investigated because they contained buildings or parking lots. Unfortunately, this information is not reflected in the transect sampling results. Instead of being classified as un-sampled areas, these areas appear as areas which were sampled, if crossed by a transect, but which contain no anomalies. Transects provided to the site characterization team in these areas reported zero anomalies and made detection of the targets and delineation of target boundaries more difficult than if these data were correctly classified as being impossible to survey. The second irregularity for this data set is in the western half of the data where there is a large concentration of UXO. This area is comprised entirely of UXO and contains no fragment anomalies. It is unexpected to have a target area with 100% UXO and no other site-related anomalies. The lack of fragment anomalies made detection of this area challenging due to the low anomaly density.

The background clutter distribution for ARA-2A appears inconsistent with the simulated site design. The background clutter is distributed over a much larger area than the range boundary itself. This leads to an overall site clutter density lower than listed as the design specification, and imparts a northeast-to-southwest gradient in the clutter density across the range. Figure B5 shows the distribution of the clutter anomalies for ARA-2A. The design specification for overall site clutter density is 25 anomalies per hectare; the actual clutter anomaly density for the area within the range boundary is 18 anomalies per hectare. This lower background density acted to make target identification from transects within this area easier than originally planned.

In a similar nature, the clutter distribution for the ARA-2B site (Figure B6) also showed some irregularities. The clutter anomalies for the western 1/3 of the site appear to be distributed over an area falling well outside of the range boundary. The intended anomaly density for this region is 10 anomalies per hectare; the measured density within the range boundary is 5.5 anomalies per hectare. This is a much larger contrast in clutter density when compared against the 15 anomaly per hectare density of the eastern 2/3's of the site. This large change in clutter density may have contributed to missing the target areas in this region during the characterization team's target delineation.

The target areas for the BGR-1 range consisted of a series of high anomaly density areas scattered across the site. Typically these were circular in nature with radii varying from 100 m to 600 m. Figure B7 shows a comparison between representative target areas from ARA-1 and ARA-2A which were designated as mortar and M155 practice ranges, and various BGR-1 targets which were designated as bombing practice targets. Of note in this figure is the relative size difference between the BGR-1 bombing targets and the other targets. Many of the BGR-1 targets areas are considerably smaller than the example mortar and M155 targets. The small size of some of the BGR-1 targets is unexpected for an aerial bombing target, particularly when compared to the size of the mortar and M155 targets from the other ranges in the simulation.

The transect designs in the 4.2" mortar sites were much tighter than necessary to attain the desired probability of traversal, but the tighter transects gave the planned transect design greater ability to detect the lower density mortar targets simulated by Mitretek. Likewise, many of the bombing and gunnery range target areas were different from the assumed target area size and shape. In the BGR-1 range the simulated target areas were smaller than the assumed target area size for the original transect designs which could have led to many unidentified target areas in the BGR-1 site. However, a few of the smaller target areas were traversed and identified by transects in the original sparse designs which lead the site characterization team to request supplemental transects over the entire BGR-1 site based on smaller target area size assumptions.

Figure B8 shows the distribution of UXO and fragment clutter for Target 1 of the BGR-1 range. As seen in this figure, a very high fraction of the anomalies are characterized as UXO, and these UXO are distributed more uniformly across the site than might be expected. In addition, the anomaly density along the outer edge of the target area is more uniformly distributed, which creates a distinct line of demarcation around the target anomalies, than might be expected. The fragmentation pattern of the outer edge from an actual target area may have a more gradational boundary that would make it more difficult to identify the edges of the target areas.

The irregularities observed in the anomaly distribution of the simulated ranges may, in some cases, have had a direct impact on the ability of the Labs to successfully delineate the simulated impact areas. Whether this impact would have resulted in greater or lesser success can only be determined through further investigation on a case-by-case basis and is beyond the scope of this report. The primary purpose of this appendix is to document these irregularities so that the results of the target identification analyses can be viewed in a proper context.

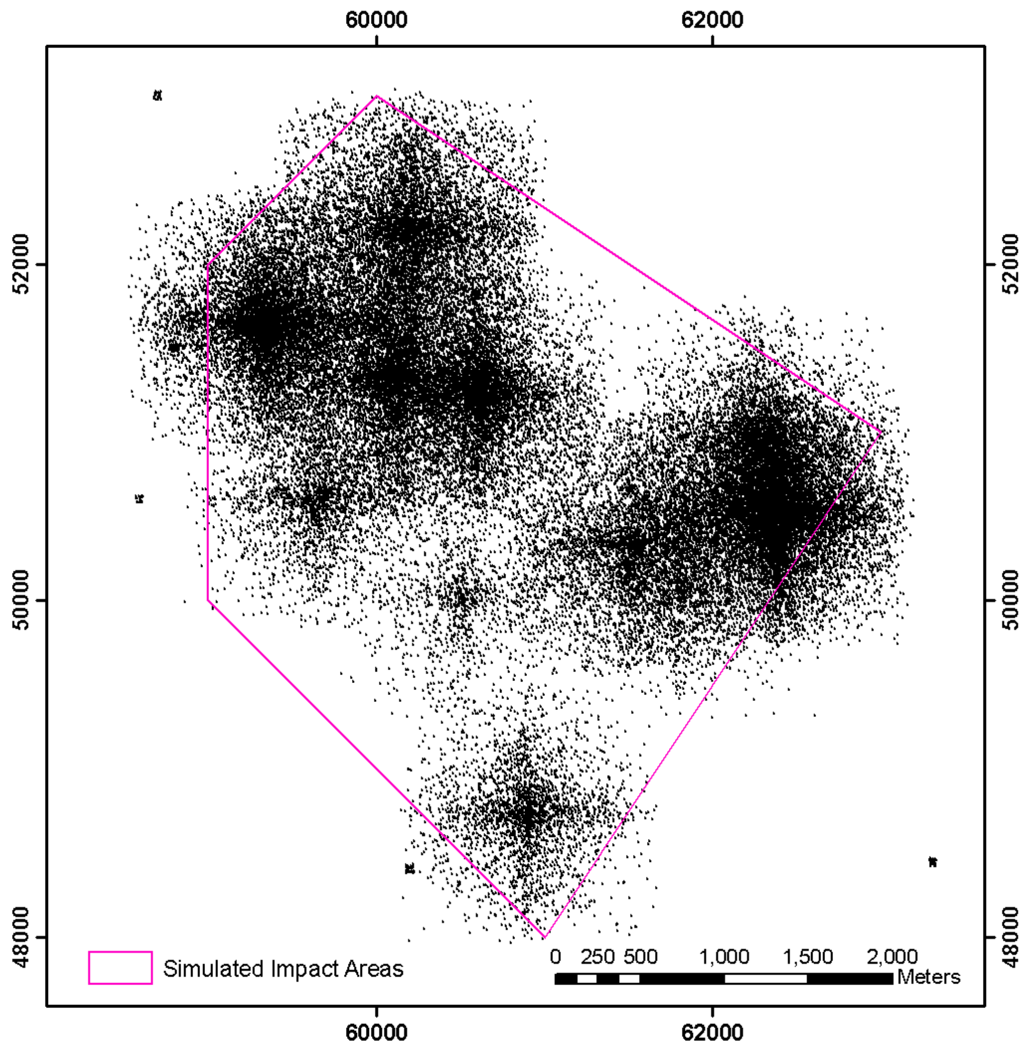

Figure B1: Spatial distribution of munitions fragments and UXO for range ARA-1. General background clutter not shown.

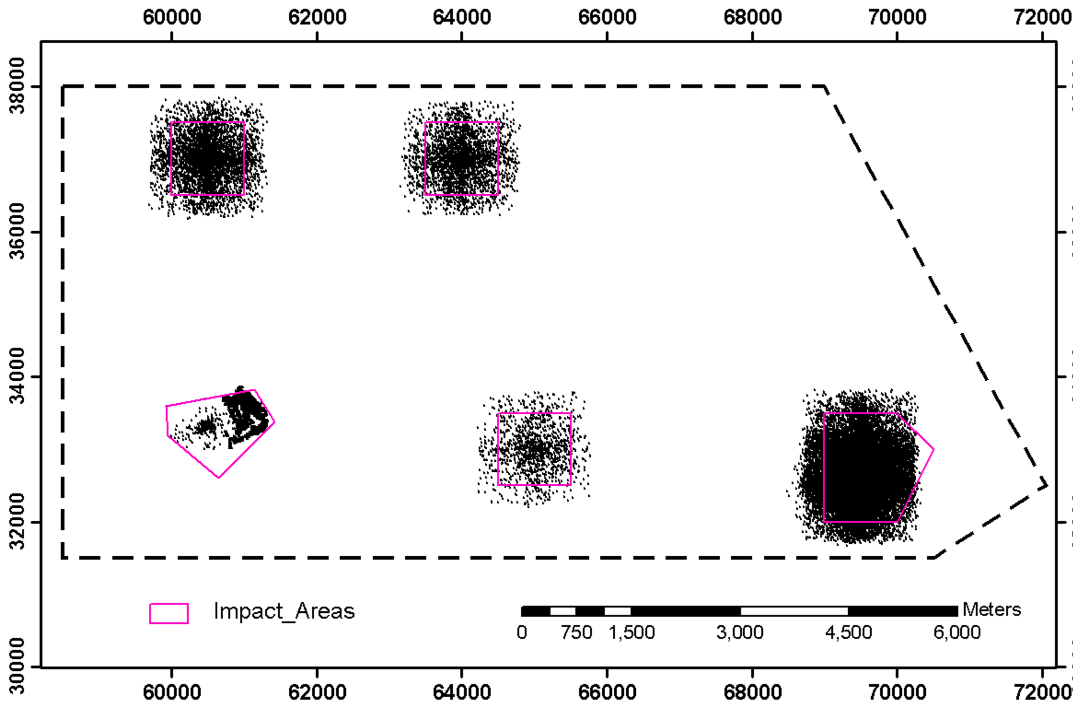

Figure B2: Spatial distribution of munitions fragments and UXO for range ARA-2A. General background clutter not shown.

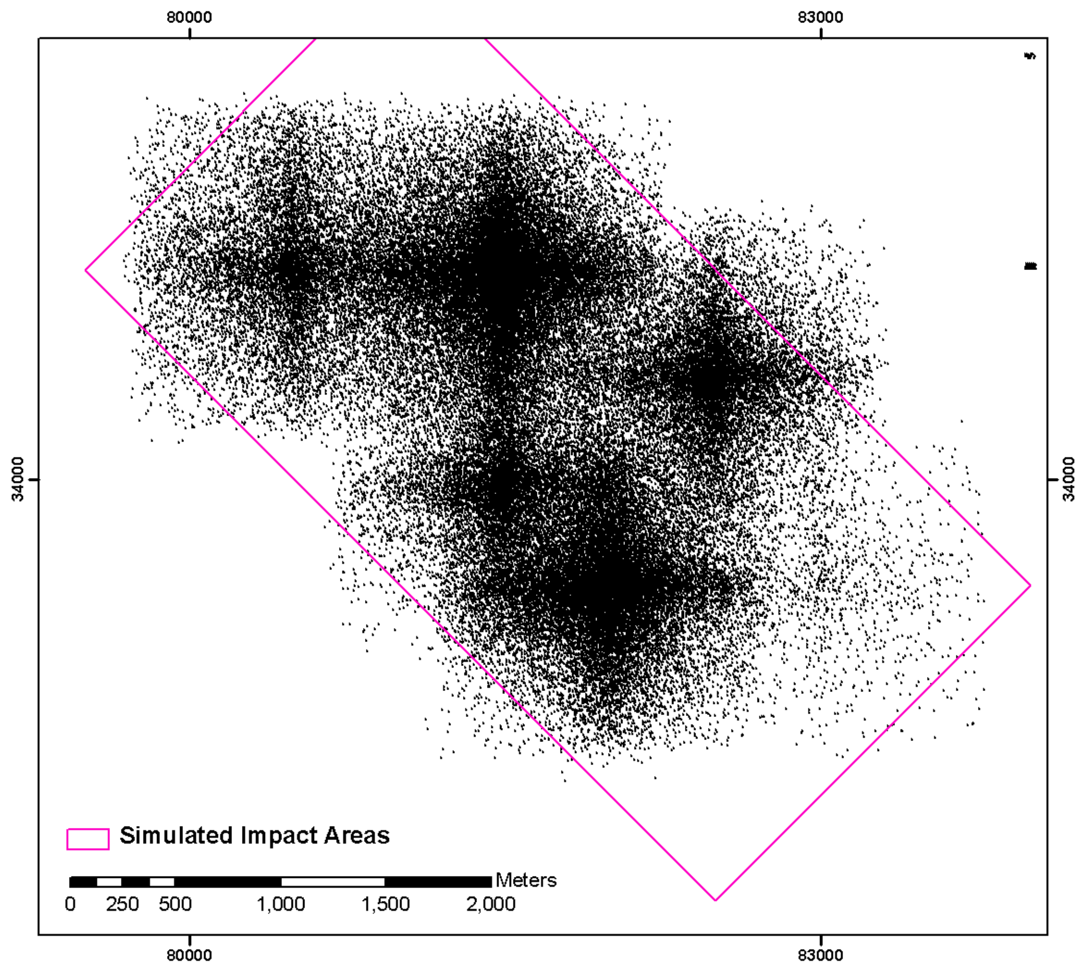

Figure B3: Spatial distribution of munitions fragments and UXO for southern target cluster of range ARA-2A. General background clutter not shown.

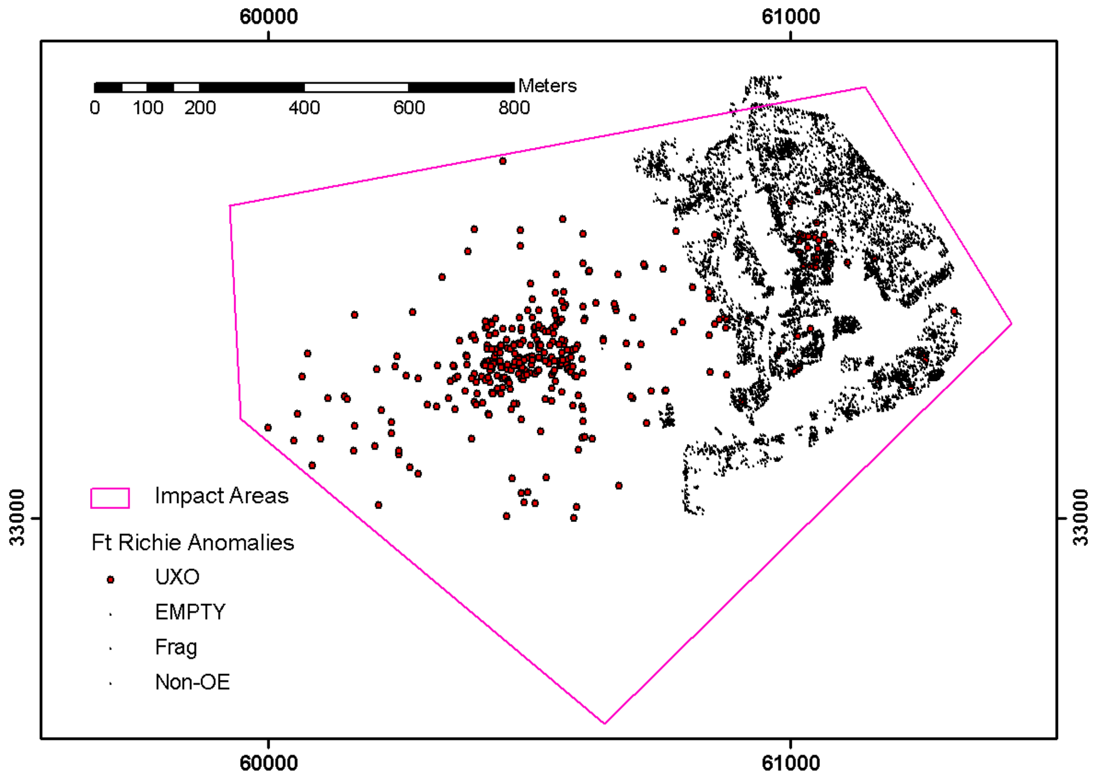

Figure B4: Distribution of anomalies for the Fort Ritchie data set as included in the ARA-2A simulated range.

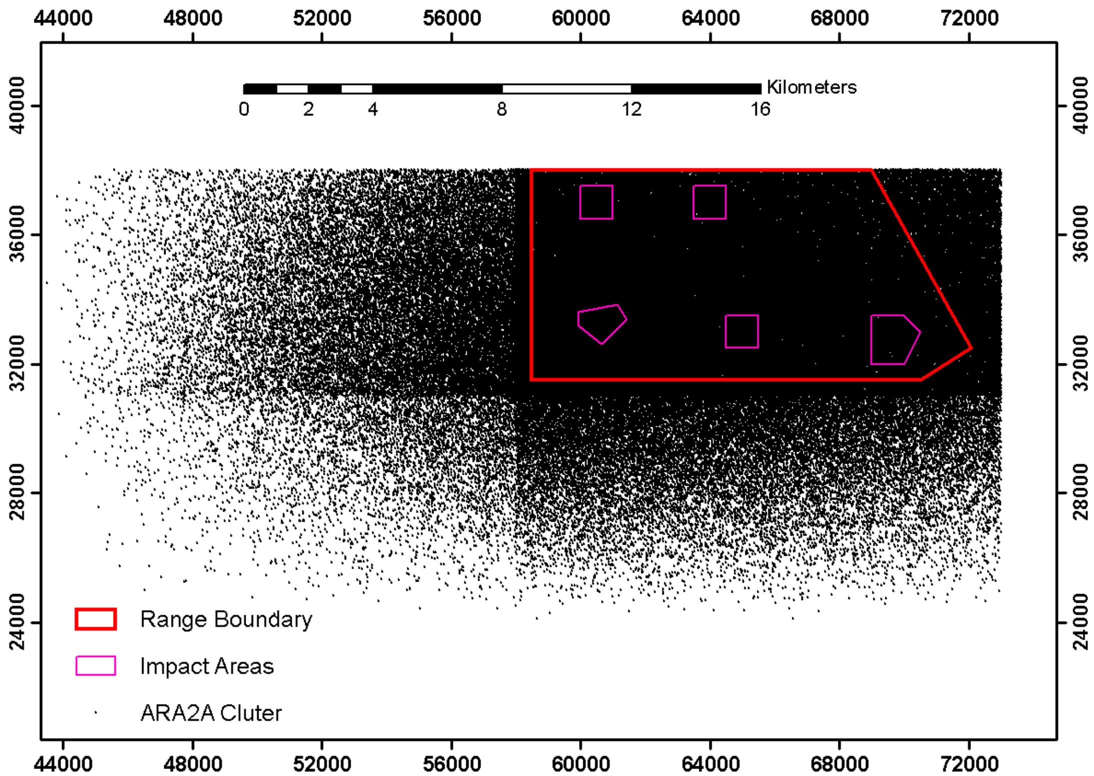

Figure B5: Background clutter density for range ARA-2A.

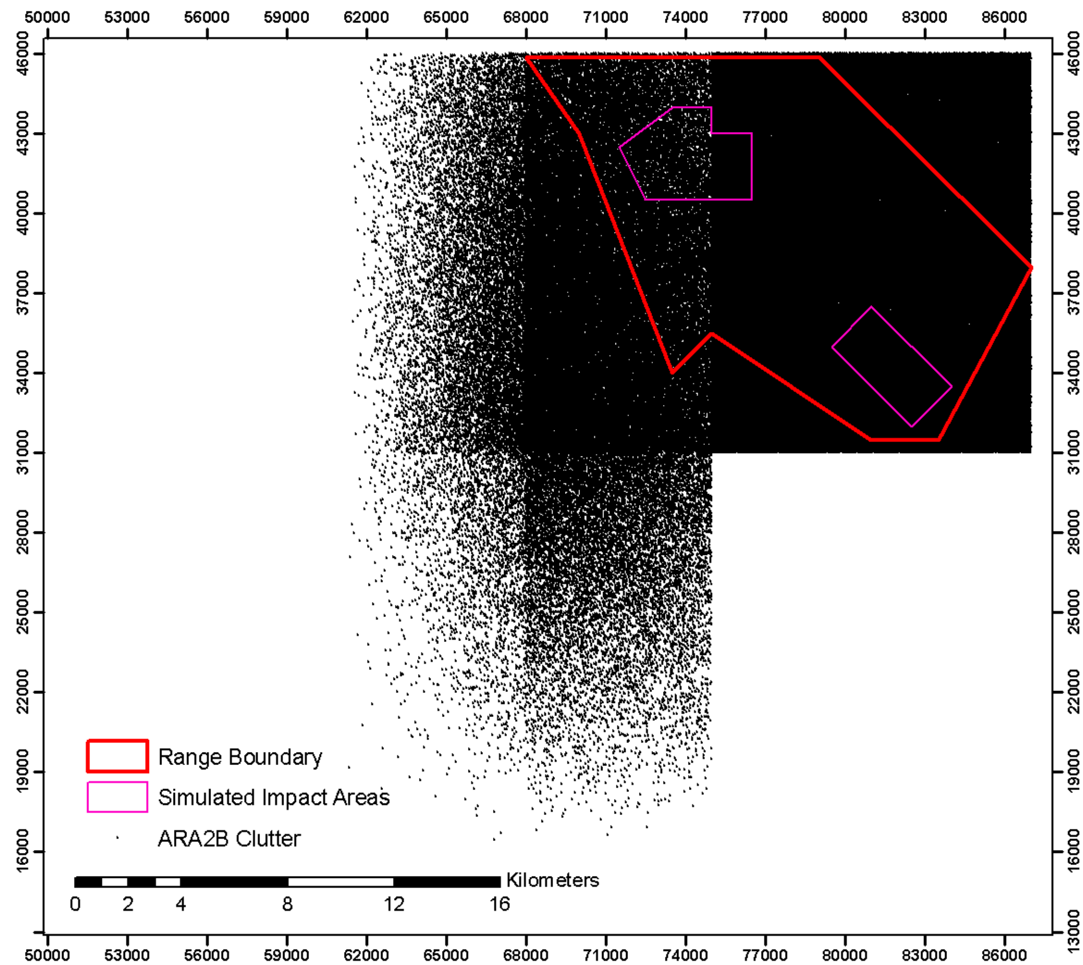

Figure B6: Background clutter density for range ARA-2B.

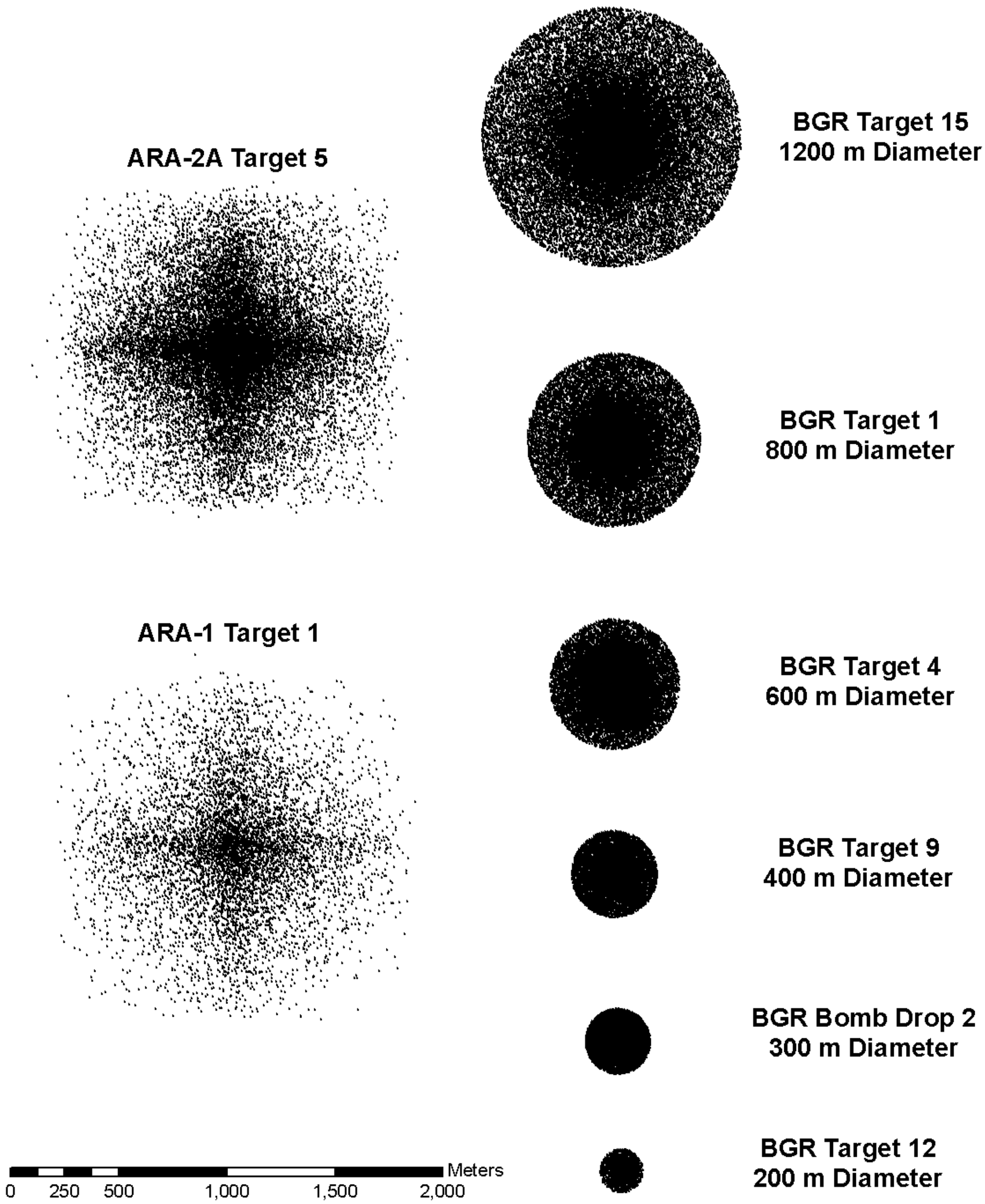

Figure B7: Comparison of different target sizes for ARA-2A, ARA-1, and BGR-1 ranges.

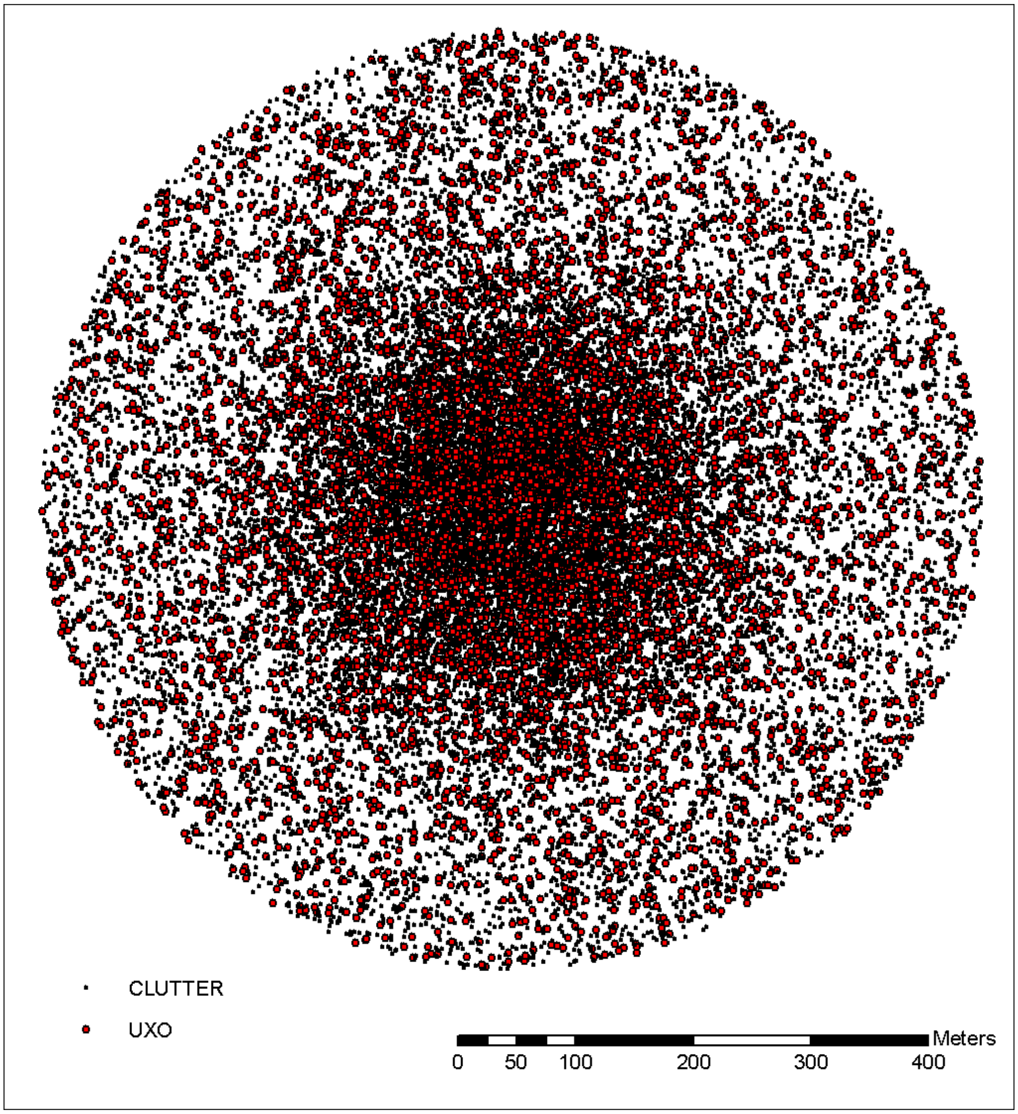

Figure B8: Distribution of UXO and fragment clutter for Target Area 1 of the BGR-1 range.